CANADIAN WOODS

their properties and uses

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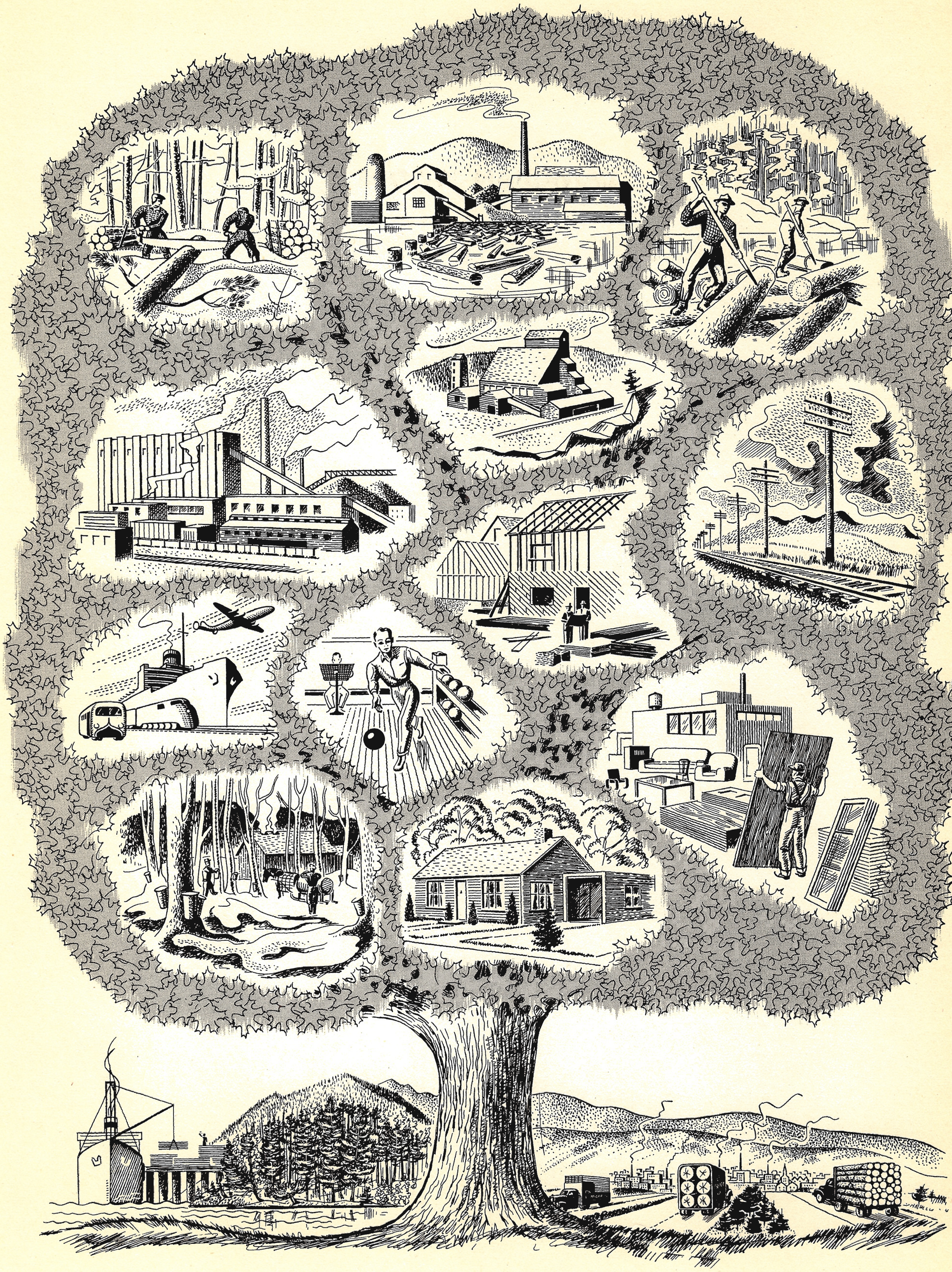

CANADIAN WOODS
their properties and uses

FORESTRY BRANCH
FOREST PRODUCTS LABORATORIES DIVISION

Issued under the authority of
THE HONOURABLE ROBERT H. WINTERS
Minister of Resources and Development

CANADIAN WOODS

their properties and uses

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AS the reader turns the pages of this book, he cannot fail to be impressed with the multifarious uses to which wood is now put, the ubiquitous part it plays in our daily lives, and the vital role it plays in our national economy. It is perhaps not putting it too strongly to say that without wood—wood in plentiful supply and in adequate variety—life as we know it today would be impossible.

The great complex of industries here considered stems from, and is utterly dependent on, the green, growing forests of Canada. But these forests have other values almost as vital to our way of life. As controllers of run-off and stream-flow, as modifiers of climate, as home and shelter of our wild-life population, as regions of beauty and tranquillity where we may relax from the stress of city life, the forests of Canada play a part in our life for which there is no substitute. And this part they can play in perpetuity, for our forests are an ever-renewable resource. Properly protected against fire, properly managed, properly harvested, their bounty will never fail.

MAY, 1951.

H. A. YOUNG
Deputy Minister

FOREWORD

THE ever-growing importance of the Canadian forests in the economy of Canada has resulted in numerous advances in most fields of utilization of the annual forest harvest. Industrial applications of wood products are of such wide variety that they permeate the very fibres of our national commerce.

The Forest Products Laboratories, now units of the Forest Products Laboratories Division of the Forestry Branch, have, since 1913, been actively engaged in research aimed at securing greater knowledge of the properties of Canadian woods and in gathering technical data essential to the orderly and economic operation and development of the various branches of wood utilization.

Research is an unending task, seldom spectacular, always progressive, and one that adds continually to the fund of basic and specific data readily available. There have been many developments since Canadian Woods—Their Properties and Uses *was first published in 1935, all intended to promote and facilitate more effective wood utilization.*

In the preparation of the present edition, the necessary data are primarily drawn from investigations at the Forest Products Laboratories. However, a publication of such wide scope must necessarily contain considerable information that is basic, and, since research generally avoids duplication of effort, many sources have been drawn on freely for relevant information.

Each chapter has been written to include only the more pertinent data, with liberal references to sources of information. Bibliographies include only material directly bearing on the subject-matter of the chapter. The aim has been to produce a volume sufficiently informative for all general purposes, and to direct the reader to sources where more extensive or more specific information can be secured.

The material has been prepared by the scientific and technical staff of the Laboratories. In the early stages the preparation was supervised by Mr. T. A. McElhanney, Superintendent of the Ottawa Laboratory, now retired. Final preparation and publication of this edition has been under the direction of Mr. J. H. Jenkins, Chief of the Forest Products Laboratories Division.

MAY, *1951.*

D. A. MACDONALD

Director of Forestry.

PREFACE

RECOGNITION *of an imperative need for forest products research was the foundation upon which rested the organization of the Forest Products Laboratories in 1913. The literature on Canadian woods, from the research viewpoint, was then very limited. Scientists and technicians who first joined the research staff entered upon an almost untrodden field with vast horizons.*

Thirty-eight years of research have contributed large stores of technical and specific data on the physical characteristics of the commercial timbers of Canada. Increased knowledge facilitates better utilization and permits development of further fields of application. The work of research goes on, seeking solutions for industrial problems, investigating possibilities for better and more complete economic utilization, and conducting studies aimed at greater knowledge of the fundamentals of wood.

Important progress has been recorded, and the accumulated knowledge now available will be of high value for future research. Research workers will continue to benefit from the contributions on record from many who were formerly associated with the Laboratories.

Valuable assistance has been given the authors of individual chapters, and general collaboration of the staff has been necessary in the preparation of this volume. Acknowledgment is particularly due to the following members of the Vancouver Laboratory:

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MAY, *1951.*

J. H. Jenkins

J. H. JENKINS

Chief, Forest Products Laboratories Division

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CANADIAN WOODS — general

by J. H. JENKINS*

WOOD has always been, and still is, one of the most valued materials for a wide variety of purposes. To primitive man it supplied fuel, shelter, weapons, and means of transport. With the development of civilization, though wood has in many instances been replaced by other materials, there has been at the same time an almost phenomenal increase in the number and variety of products manufactured from it either directly or indirectly.

Many factors have contributed to the continued usefulness and popularity of wood, among the more important of which might be mentioned the following: its ease of working with machines and tools to any desired size or shape; its beauty of figure; its high insulating value with respect to sound and heat; the ease with which it may be bent or twisted to special shapes; the readiness with which it can be framed or otherwise fastened by screws, nails, dowels, or glue; its durability, save under conditions favouring decay; its paint-taking and paint-holding properties; its freedom from rust and corrosion; the ease with which it can be salvaged and re-used; its ability to absorb shock from suddenly applied loads, and many other factors of greater or lesser importance. Not least among the advantages of wood is the fact that the forest is renewable as a crop, and so may afford a continuous supply of timber.

In the past, when uses for wood were limited, and means of transportation for long distances were not available, the uses to which it was put were governed largely by local requirements and by such species as were readily available. Because of the great abundance of wood of many species in Canada, material of the finest quality was available for any demand. With increasing diversity in the uses to which wood is put, and with the great expansion in transportation and distribution facilities, uses have been found for nearly all species of commercial size. Lumber and lumber products have taken a place among the most important commodities in international trade, and it has become necessary to develop systems of grading which will ensure that the best use may be made of wood products.

While Canada has not so great a variety of species as some countries, especially those situated within the tropics, it has, nevertheless, quite a wide range of both hardwoods and softwoods, many of which are of commercial importance. From the standpoint of number of species, the hardwoods or broad-leaved species predominate, but about 80 per cent of the total quantity of standing timber consists of softwoods or coniferous species. Exclusive of fuelwood, about 95 per cent of the commercial cut consists of softwoods. It is not intended in this publication to deal specifically with the minor species which are of no importance in either the domestic or export market.

*In bringing this chapter up to date, extensive use has been made of the original material prepared by Mr. T. A. McElhanney for the first edition.

MERCHANTABLE TIMBER, BY PROVINCES — 1949

In Commercial Units of Measurement

TABLE 1

PROVINCE		SAW-TIMBER(1) (Millions Ft. b.m.)	SMALLER(2) MATERIAL (Thousands of Cords)	TOTAL (Thousands of Cubic Feet)
PRINCE EDWARD ISLAND	Softwood	65	560	60,600
	Hardwood	40	240	28,400
	Total	105	800	89,000
NOVA SCOTIA	Softwood	4,849	23,167	2,938,995
	Hardwood	1,261	5,363	708,055
	Total	6,110	28,530	3,647,050
NEW BRUNSWICK	Softwood	5,000	60,000	6,100,000
	Hardwood	1,500	30,000	2,850,000
	Total	6,500	90,000	8,950,000
MARITIME PROVINCES	Softwood	9,914	83,727	9,099,595
	Hardwood	2,801	35,603	3,586,455
	Total	12,715	119,330	12,686,050
QUEBEC	Softwood	51,024	856,320	82,992,000
	Hardwood	14,579	218,468	21,485,580
	Total	65,603	1,074,788	104,477,580
ONTARIO	Softwood	42,975	270,515	31,588,775
	Hardwood	11,529	300,380	27,838,100
	Total	54,504	570,895	59,426,875
QUEBEC AND ONTARIO	Softwood	93,999	1,126,835	114,580,775
	Hardwood	26,108	518,848	49,323,680
	Total	120,107	1,645,683	163,904,455
MANITOBA	Softwood	935	10,856	1,109,760
	Hardwood	1,630	19,712	2,001,520
	Total	2,565	30,568	3,111,280
SASKATCHEWAN	Softwood	660	6,250	663,250
	Hardwood	1,265	54,230	4,862,550
	Total	1,925	60,480	5,525,800
ALBERTA	Softwood	12,730	142,750	14,679,750
	Hardwood	4,650	92,500	8,792,500
	Total	17,380	235,250	23,472,250
PRAIRIE PROVINCES	Softwood	14,325	159,856	16,452,760
	Hardwood	7,545	166,442	15,656,570
	Total	21,870	326,298	32,109,330
BRITISH COLUMBIA COAST	Softwood	155,129	24,462	29,226,845
	Hardwood	—	—	—
	Total	155,129	24,462	29,226,845
BRITISH COLUMBIA INTERIOR	Softwood	99,370	506,952	60,480,670
	Hardwood	—	—	—
	Total	99,370	506,952	60,480,670
BRITISH COLUMBIA PROVINCE	Softwood	254,499	531,414	89,707,515
	Hardwood	—	—	—
	Total	254,499	531,414	89,707,515
NORTHWEST AND YUKON TERRITORIES	Softwood	6,100	12,300	2,265,500
	Hardwood	—	21,000	1,785,000
	Total	6,100	33,300	4,050,500
CANADA (3)	Softwood	378,837	1,914,132	232,106,145
	Hardwood	36,454	741,893	70,351,705
	Total	415,291	2,656,025	302,457,850

[1]To convert thousand feet board measure to cubic feet of merchantable timber, multiply by 175 for British Columbia, and by 200 for other Provinces.

[2]To convert cords of smaller material to cubic feet of merchantable timber, multiply by 85.

[3]Excluding Newfoundland.

MERCHANTABLE TIMBER, BY SPECIES — 1949*
In Commercial Units of Measurement

TABLE 2

SOFTWOODS	SAW-TIMBER (Millions Ft. b.m.)	SMALLER MATERIAL (Thousands of Cords)	TOTAL M Cu. Ft. Merchantable Timber	PRINCIPAL PRODUCING REGION
SPRUCE	125,823	921,023	102,196,005	All Canada
BALSAM FIR	50,207	394,539	42,790,115	All Canada
DOUGLAS FIR	49,519	23,391	10,660,310	British Columbia
HEMLOCK	58,514	21,961	12,152,935	British Columbia and Eastern Provinces
WHITE PINE	9,733	9,928	2,751,680	Eastern Provinces and British Columbia
RED PINE	425	2,334	283,390	Eastern Provinces
JACK AND LODGEPOLE PINES	27,483	511,836	48,758,110	All Canada
PONDEROSA PINE	1,383	5,185	682,750	British Columbia
CEDAR	50,394	18,038	10,386,930	British Columbia and Eastern Provinces
LARCH	2,337	5,469	879,215	All Canada
YELLOW CEDAR	3,019	428	564,705	British Columbia
TOTAL SOFTWOODS	378,837	1,914,132	232,106,145	
TOTAL ACCESSIBLE SOFTWOODS	209,003	1,069,523	129,966,605	
HARDWOODS				
POPLAR	15,106	336,211	31,599,135	All Canada
WHITE BIRCH	9,730	246,819	22,925,615	All Canada
YELLOW BIRCH	6,154	61,205	6,433,225	Eastern Provinces
MAPLE	4,203	65,979	6,448,815	Mostly Eastern Provinces
BEECH	465	21,255	1,899,675	Eastern Provinces
ELM	121	1,965	191,225	" "
ASH	171	4,207	391,795	" "
BASSWOOD	136	2,500	239,700	" "
OAK	47	517	53,345	Mostly Eastern Provinces
OTHER HARDWOODS	321	1,235	169,175	" " "
TOTAL HARDWOODS	36,454	741,893	70,351,705	
TOTAL ACCESSIBLE HARDWOODS	33,069	617,311	59,085,235	
TOTAL MERCHANTABLE TIMBER	415,291	2,656,025	302,457,850	
ACCESSIBLE TIMBER	242,072	1,686,834	189,051,840	

*Excluding Newfoundland.

TIMBER RESOURCES

OF a total land area in Canada of 3,462,103 square miles (excluding Newfoundland), it is estimated that 1,274,840 square miles are forested land which can be used to greatest economic advantage by perpetuating its use for the production of successive crops of timber. Not all of this land is, under present conditions, accessible for the commercial exploitation of its forests, nor is it all capable of producing timber of commercial size. The total productive forest area is about 701,232 square miles, of which 294,180 square miles are supporting timber of merchantable size, and the remaining 407,052 square miles young forest which, with protection from fire, insects, and disease, will eventually produce commercial timber. The remaining forest land, consisting of 573,608 square miles, will not, because of unsuitable conditions of growth, produce timber of commercial value, but will produce a crop of small timber, of importance for its influence on climatic conditions and water supply or for the protection of game.

Canada is preponderantly a softwood country, though containing much valuable hardwood. Of the productive area, it is estimated that about

PRINCIPAL STATISTICS OF THE FOREST INDUSTRIES — 1946, 1947, 1948

TABLE 3

		Woods Operations	Lumber Industry	Pulp and Paper Industry	Wood-using Industries	Paper-using Industries**	Total All Industries
NUMBER	1946	138,793	49,352	44,967	58,377	22,474	313,963
OF	1947	145,247	55,426	49,946	67,484	23,499	341,602
EMPLOYEES*	1948	148,223	56,756	51,924	69,661	24,056	350,620
SALARIES	1946	277,000,000	63,811,260	101,364,636	81,483,876	32,955,910	556,615,682
AND	1947	340,000,000	83,360,452	129,477,995	106,766,860	39,154,399	698,759,706
WAGES	1948	347,000,000	95,065,676	151,662,761	123,105,331	45,735,049	762,568,817
COST OF FUEL	1946		2,394,138	46,202,000	3,693,113	1,653,168	53,942,419
AND	1947		3,074,589	55,442,396	4,568,964	1,965,412	65,051,361
ELECTRICITY	1948		3,763,106	63,843,111	5,098,914	2,286,232	74,991,363
COST OF	1946	88,815,451	156,107,527	223,448,338	144,323,604	89,962,318	702,657,238
MATERIAL	1947	112,485,206	208,543,819	295,444,332	193,531,186	115,012,238	925,016,781
OR SERVICES	1948	125,562,426	208,568,170	349,244,083	223,652,196	135,993,344	1,043,020,219
NET VALUE	1946	324,453,863	129,408,392	258,164,578	130,875,178	75,655,132	918,557,143
OF	1947	407,318,922	190,514,890	356,084,900	179,193,934	87,289,535	1,220,402,181
PRODUCTION	1948	460,732,642	196,936,196	412,770,470	209,260,759	97,222,567	1,376,922,634
GROSS VALUE	1946	413,269,314	287,910,057	527,814,916	278,891,895	167,270,618	
OF	1947	519,804,128	402,133,298	706,971,628	377,294,084	204,267,185	
PRODUCTION	1948	586,295,068	409,267,472	825,857,664	438,011,869	235,502,143	

*Number of Employees on man-year basis — 300 days.
**Does not include the printing trades.

381,180 square miles carry softwood stands, about 215,085 square miles mixedwood, and about 104,967 square miles hardwood stands.

Though complete, detailed surveys of all Canada's timber resources have not yet been made, estimates have been compiled through the joint effort of the Federal and Provincial Forest Services. The latest estimates available place the total amount of merchantable timber in Canada at 302,458 million cubic feet, of which amount 189,052 million cubic feet are considered accessible to existing means of transportation. Of this accessible amount, 242,072 million board feet are large enough to be classed as saw material; the remainder, 1,687 million cords, being chiefly immature timber, is suitable at present only for fuelwood, pulpwood, fencing, and similar uses.

The estimated amount of merchantable timber in Canada is shown by provinces in Table 1.

ANNUAL PRODUCTION OF PRIMARY FOREST PRODUCTS — 1946, 1947, 1948

TABLE 4

		1946		1947		1948	
PRODUCT	Commercial Unit	Commercial Units	Merchantable Timber	Commercial Units	Merchantable Timber	Commercial Units	Merchantable Timber
		No.	M cu. ft.	No.	M cu. ft.	No.	M cu. ft.
LOGS AND BOLTS	M ft. b.m.	5,603,944	1,072,413	6,525,204	1,245,989	6,561,186	1,250,416
PULPWOOD	Cords	10,523,256	894,476	11,484,522	976,184	12,497,926	1,062,324
FUELWOOD	Cords	9,102,452	728,196	9,297,560	743,805	9,529,510	762,361
POSTS	Number	18,810,803	22,573	17,197,664	20,637	15,970,223	19,164
HEWN TIES	Number	1,042,054	5,210	1,009,961	5,049	968,476	4,842
FENCE RAILS	Number	5,087,190	5,087	5,127,790	5,128	5,039,529	5,039
ROUND MINING TIMBER	Cu. ft.	30,564,858	30,565	39,640,055	39,640	37,728,802	37,729
WOOD FOR DISTILLATION	Cords	43,411	3,473	53,613	4,289	45,359	3,629
POLES AND PILING	Number	830,911	12,464	1,020,163	15,302	1,029,158	15,437
MISCELLANEOUS PRODUCTS*	Dollars	6,972,509	38,261	7,177,790	35,063	8,726,895	37,238
TOTAL—All Products			**2,812,718**		**3,091,086**		**3,198,179**

*Miscellaneous Products include bolts, blocks, billets, square timber, waney timber, boom timbers, masts and spars, knees and futtocks, hop poles, Christmas trees, tan-bark, etc.

FOREST INDUSTRIES

THE three primary forest industries of Canada are woods operations (or logging), the lumber industry, and the pulp and paper industry. In addition to these main industries, there are large and important groups of secondary industries which use partially manufactured wood, pulp, or paper as their principal raw materials and are known as the wood-using and paper-using industries.

Since the products of one branch of the forest industries may be used as the raw materials of another, the gross or sale value of production contains duplication of values. In order to determine the contribution of the forest industries as a group to the national output of wealth, it is necessary to use the net value of production of each of them. This is obtained by subtracting from the gross value the cost of materials and supplies used and the cost of fuel and purchased power. For the years 1946, 1947, and 1948, the annual contributions of the forest industries to the national wealth were, respectively $918,557,143, $1,220,402,181, and $1,376,922,634.

The output in 1948 of primary forest products amounted to 3,198,179 M cubic feet of merchantable timber, an increase of 3 per cent over the total for 1947 and 14 per cent over the total for 1946 (Table 4). Exports of these unmanufactured products reached 280,241 M cubic feet in 1948, nearly 9 per cent of production. Imports of unmanufactured wood amounted to 19,676 M cubic feet during the same year. The apparent domestic consumption of primary products totalled 2,937,614 M cubic feet in 1948—3 per cent above that of 1947, and 14 per cent above that of 1946.

Production figures for lumber in 1948 show that Canadian sawmills manufactured 5,908,798 M ft. b.m. in that year—a record production figure, 30,897 M ft. b.m. more than in 1947 and 825,518 M ft. b.m. more than in 1946 (Table 5). During the year 1948, lumber exports reached 2,467,740 M ft. b.m. and imports amounted to 42,919 M ft. b.m.;

ANNUAL PRODUCTION OF LUMBER, BY SPECIES — 1946, 1947, 1948

TABLE 5

SPECIES	1946	1947	1948
	M ft. b.m.	M ft. b.m.	M ft. b.m.
SOFTWOODS			
SPRUCE	1,782,598	2,011,659	1,982,084
DOUGLAS FIR	1,128,325	1,410,177	1,514,118
HEMLOCK	589,091	657,016	651,476
WHITE PINE	351,490	385,805	379,316
CEDAR	221,860	302,710	308,889
JACK AND LODGEPOLE PINES	236,345	233,762	252,781
BALSAM FIR	129,019	142,031	137,495
RED PINE	62,121	67,256	65,567
LARCH	44,259	48,044	65,698
PONDEROSA PINE	18,366	35,783	34,904
YELLOW CEDAR	1,433	3,600	6,479
HARDWOODS			
YELLOW BIRCH	187,353	212,718	180,611
MAPLE	103,971	112,002	111,911
POPLAR	67,027	87,472	67,311
WHITE BIRCH	44,465	46,240	41,050
BASSWOOD	33,028	38,304	34,609
ELM	23,037	24,799	23,773
BEECH	9,643	11,353	10,890
OAK	8,144	8,496	8,861
ASH	4,864	5,757	5,365
OTHER HARDWOODS	35,939	32,234	24,854
TOTAL SOFTWOODS	4,564,907	5,297,843	5,398,807
TOTAL HARDWOODS	517,471	579,375	509,235
TOTAL UNSPECIFIED	902	683	756
GRAND TOTAL	5,083,280	5,877,901	5,908,798

the apparent consumption in Canada for the same year therefore amounted to 3,483,977 M ft. b.m., or 270 ft. b.m. of lumber per capita.

Pulp mills in Canada manufactured 7,675,079 tons of wood pulp in 1948 as compared with 7,253,671 tons in 1947 and 6,615,410 tons in 1946 (Table 6). Exports of wood pulp during 1948 reached 1,797,998 tons—or more than 23 per cent of production. During the same year, Canada imported 33,004 tons of wood pulp, resulting in an apparent consumption in Canada of 5,910,085 tons in 1948.

The production of paper in Canadian mills reached a record of 6,063,646 tons in the same year. This compares with production of 5,775,082 tons in 1947 and 5,347,118 tons in 1946 (Table 7). Of the 1948 production figure, newsprint accounted for 4,640,336 tons, or more than 76 per cent. During the same year Canadian mills exported 4,328,084 tons of newsprint—or 93 per cent of newsprint production.

ANNUAL PRODUCTION OF WOOD PULP — 1946, 1947, 1948

TABLE 6

WOOD PULP	1946 Quantity—tons	1946 Value—$	1947 Quantity—tons	1947 Value—$	1948 Quantity—tons	1948 Value—$
GROUNDWOOD	3,997,848	111,514,231	4,275,269	147,423,552	4,413,513	168,343,496
SULPHITE, BLEACHED	616,797	58,859,624	704,749	85,671,202	731,653	99,052,519
SULPHITE, UNBLEACHED	1,213,220	76,000,948	1,322,783	102,483,191	1,406,358	121,374,466
SULPHATE	562,233	35,246,426	689,435	59,303,735	815,076	84,754,779
SCREENINGS	135,153	2,131,123	151,588	3,363,212	152,995	3,380,969
OTHER PULP	90,159	3,871,875	109,847	5,608,343	155,484	9,059,935
TOTAL	6,615,410	287,624,227	7,253,671	403,853,235	7,675,079	485,966,164

ANNUAL PRODUCTION OF PAPER — 1946, 1947, 1948

TABLE 7

PAPER	1946 Quantity—tons	1946 Value—$	1947 Quantity—tons	1947 Value—$	1948 Quantity—tons	1948 Value—$
NEWSPRINT	4,162,158	280,809,610	4,474,264	355,540,669	4,640,336	402,099,718
BOOK AND WRITING PAPER	189,318	29,995,156	210,762	39,727,187	231,608	45,178,968
WRAPPING PAPER	175,369	20,797,070	188,742	26,009,996	207,128	31,036,805
PAPERBOARD	683,643	50,213,833	744,377	66,126,302	817,432	80,864,700
TISSUE PAPER	56,717	9,015,540	67,506	12,179,656	69,686	13,927,917
MISCELLANEOUS PAPER	79,913	6,125,181	89,431	7,517,467	97,456	9,238,734
TOTAL	5,347,118	396,956,390	5,775,082	507,101,277	6,063,646	582,346,842

STANDARDS OF MEASUREMENT

Canada and the United States

LUMBER.—Board measure is the term used to indicate that a board foot is the unit of measurement. A board foot is the quantity of lumber contained in (or derived from) a piece of rough, green lumber, 1 inch thick, 12 inches wide, and 1 foot long, or its equivalent in thicker, wider, narrower, or longer lumber.

Except moulding, which is tallied in linear feet, lumber is tallied "board measure". The measurement of rough, dry or of dressed lumber is based on the corresponding nominal dimensions of rough, green lumber. The measurement of lumber less than 1 inch in thickness is based on the surface dimensions, i.e., width and length without regard to thickness.

To determine the board-foot content of lumber thicker than 1 inch, the surface measure is multiplied by the nominal thickness in inches and fractions of an inch.

LOG MEASURE.—In the case of provincial stumpage dues, and the marketing of sawlogs in Canada and the United States, the content of the logs is expressed in board feet for recording and quotation purposes.

A number of log rules are in use for the measuring of the board-footage of logs. In Canada, each of the important lumber-producing prov-

inces has its own log rule, based on formulae or on empirical tables, and designed to allow for such factors as the taper of the tree stems, percentage of salable material in the logs, and the gauge of the saws in use in that area. Particulars of these log rules may be found in the booklet, Form-class Volume Tables, issued by the Federal Forestry Branch.

SHINGLES.—Shingles may be sold by the thousand or by the "square pack". Present practice favours the latter system. In the square pack, the shingles are packed in such a way that a prescribed number of bundles, at a specified exposure of the shingles to the weather, will cover an area of 100 square feet, known as a "square".

Shingles are usually cut in lengths of 16 inches, 18 inches, and 24 inches, though "shakes" (large split shingles) may be cut in longer lengths, usually 32 inches.

The thickness of shingles is gauged by the thickness of the butts, and is designated by the number of shingle butts required to make a thickness of a specified number of inches. The expression "5 butts, 2 inches," or "5/2" signifies that the total thickness of the butts of five shingles is 2 inches.

Shingles are packed in forms of fixed width, edge to edge, with the thin ends overlapping. The layers at each end of the bundle are known as "courses", and the total number of courses multiplied by the width of the pack is expressed as "running inches". The number of running inches required for a square varies with the exposure allowance in laying.

LATH.—Laths are sold by the thousand pieces, and are generally manufactured in lengths which are multiples of 16 inches, usually 32 or 48 inches, since 16 inches is the ordinary centre-to-centre distance between the studs to which the laths are nailed. Laths are generally manufactured 1½ inches or 1⅝ inches in width and three-eighths of an inch in thickness, though thinner and narrower ones are also made. They are usually packed 50, but sometimes 100, to the bundle.

PULPWOOD.—Pulpwood is usually cut in 4- or 8-foot lengths and sold by the cord, a pile of wood 4 feet by 4 feet by 8 feet or an equivalent volume. There are a number of exceptions to this rule, however, in certain provinces, where the log contents are measured in board feet.

The unit of measurement for pulpwood cut on Crown lands is governed by provincial regulations with regard to royalties on such timber.

RAILWAY TIES.—Railway ties are commonly divided into two classes, track ties and switch ties. Track ties for steam railways are all 8 feet in length, and, though no standard specifications exist in Canada, usually they are graded into three grades for each of the flatted (hewn) and squared (sawn) types. These grades are known as No. 1, No. 2, and No. 3 or Merchantable Cull. No. 1 and No. 2 grades are of the same quality but of different dimensions in cross-section. The No. 1 tie is 7 inches thick, the face of the squared tie being 9 inches wide and of the hewn tie 7 to 12 inches wide. The No. 2 tie is 6 inches thick, the face of the squared tie being 8 inches wide and of the hewn tie 6 to 12 inches wide. The No. 3 or Merchantable Cull grade consists of ties which are larger or smaller than the No. 1 or No. 2 ties, and permits certain defects not acceptable in these grades. Specifications are not, in all respects, standard for different railways.

Switch ties do not vary in thickness or width, but are of different lengths. They are 7 inches thick, 9 inches wide, and from 9 feet to 16 feet in length. All switch ties are sawed to dimension, and permissible defects in manufacture or material are similar to those specified for track ties.

Electric railways of standard gauge usually specify ties of the same length as those used by steam railways, but of slightly less thickness and width. The standard tie of the American Electric Railway Association is 8 feet in length, 8 inches in width, and 6 inches in depth, and this is the standard generally adopted in Canada.

POLES (telephone and telegraph).—Canadian Standards Association specifications for poles have been established for eastern cedar, western red cedar, red pine, jack pine, lodgepole pine, and Douglas fir. Poles are graded into classes determined by size, straightness, knots, taper, and other factors. They are usually 20 feet or more in length and are sold by the piece. Size is determined by length and by diameters (or circumferences) at the tip and at the ground-line.

PILING.—Piling is cut in lengths of 15 feet and up, generally in multiples of 5 feet. Sizes are specified by limiting diameters or circumferences at the tip and butt. Three classes of pile are specified—Class A, Class B, and Class C. Class A and Class B differ in size only; Class C differs from Classes A and B both in size and quality.

Piling is usually sold on a linear-foot basis, though it may be sold by the piece. Standard specifications for wood piling (A56-1942) are published by the Canadian Standards Association.

VENEERS AND PLYWOOD.—Veneers and plywood are always sold on the superficial-foot or face-dimension basis, regardless of the thickness.

MOULDINGS.—Mouldings used in interior or exterior trim are sold by the linear foot.

United Kingdom

LUMBER

In the softwood market of the United Kingdom, the basis of measurement is the "Standard", a unit fixed by a number of pieces, usually 120, of certain fixed dimensions. In the past there have been many standards in use, including the Quebec Standard, which governed the shipment of Canadian softwoods—mostly white pine. While this unit is no longer in use, it is of interest to note that the Quebec Standard was made up of 100 pieces, 10 feet long, 11 inches wide, and 3 inches thick, or 2,750 feet board measure.

PETROGRAD STANDARD.—Other standards have gradually disappeared, until at the present time the Petrograd Standard is the basis of measurement for all softwoods in the United Kingdom. The Petrograd Standard was originally made up of 120 pieces of lumber, 12 feet long, 11 inches wide, and 1½ inches thick, or 6 feet long, 11 inches wide and 3 inches thick, the equivalent of 1,980 feet board measure. This standard now represents 1,980 feet board measure of lumber in any dimensions and from any part of the world.

The Petrograd Standard may be broken up into quarters, deals, and parts, but because the method of computing these divisions is complicated they are seldom used, the custom being to carry the number of standards to three decimal places. The Petrograd Standard contains 165 cubic feet, or 4.672 cubic metres.

LOAD.—Square timber (softwoods and some hardwoods) is usually measured by the "Load", and, in addition to this, softwood timbers of all dimensions, and staves, plywood, pit-props (hardwood or softwood), railway ties, and veneer wood are recorded in loads in the Board of Trade Statistical Reports.

One load of round (unhewn) timber contains 40 cubic feet. One load of square-edged timber contains 50 cubic feet or 600 feet board measure; 3.3 loads equal one standard.

SHIPPING TON.—The British Shipping Ton is equivalent to 42 cubic feet of timber. This "ton" has no relation to the "long ton" of 2,240 pounds, used as a basis of quotation for such woods as satinwood, rosewood, lignum vitae, and ebony.

FATHOM.—The fathom is used for measuring such products as lathwood and pit-props. It measures 6 by 6 by 6 feet, or 216 cubic feet.

STACK.—A stack of wood measures 3 feet by 3 feet by 12 feet, or 108 cubic feet, one-half a fathom.

CUBIC FOOT.—The cubic foot, equivalent to 12 board feet, is a unit of measurement for round and waney logs and for square timber. In the domestic trades in the United Kingdom, it is also frequently used for measuring deals, flitches, and other timbers of large cross-section. For statistical purposes, the volume of material classified by board feet, standards, and certain other units of measurement is frequently reduced to cubic feet.

LOG MEASURE

In the measurement of logs in Great Britain, the "String Measure" is the method used by the Customs. The circumference of the log at its centre is measured in inches by a string or girthing tape; one-quarter of this circumference is squared and multiplied by the length of the log in feet; the product is divided by 113, and carried to three places of decimals, the result being in cubic feet. Very often the "Hoppus System" is used in the trade because of long-established practice. In this system the same measurements are used, but 144 is used instead of 113 as the divisor.

The "Liverpool String Measure" is the same as the String Measure-Hoppus system, but it definitely sets down that the girth or circumfer-

ence be measured to the quarter-inch and the length to the half-foot and computed to cubic feet and twelfths. If measured over the bark, allowance is made for bark as follows: one-half inch for 11¾ inches and under, one inch for 12 to 17¾ inches and under, and an additional half inch for every six inches or part thereof over 17¾ inches.

Other Countries

In most parts of Europe and South America the metric system is used, and with few exceptions the cubic metre is the basis of measurement for lumber, and the square metre for veneers, flooring, etc. The cubic metre is equivalent to 35.3 cubic feet or 0.214 of a standard. In the measurement of pulpwood, one stère is equivalent to 0.75 cubic metre. For plywood, 5mm. thick, 1,000 square metres are equivalent to 5.00 cubic metres or 177 cubic feet.

In Australia and New Zealand the board foot is used practically as much as in America; in South Africa, British practice is followed in the use of the Petrograd Standard for softwoods and cubic feet for hardwoods.

Converting factors for use in the measurement of forest products have been approved for the use of F.A.O.* by international conferences on forest statistics held in Washington and Rome in 1947. They are published in the Year Book of Forest Products Statistics issued by F.A.O., Washington, D.C.

LUMBER GRADES

Canadian lumber is not marketed in Canada only but is exported to many countries, each of which has its own particular requirements and specifications governing them. The grading of lumber in a mill serving both the domestic and export markets is, therefore, a somewhat complex matter. Even in the domestic market, because of the different uses for which the various species are suited, it is impracticable to adopt uniform grading rules for all species.

In general, therefore, lumber associations or groups interested in particular species have established their own grading rules. For the more important species, serving a variety of uses, grades have been very carefully defined. For others, especially in the case of the smaller mills, the mill cut may be sold on a mill-run basis, the wholesaler or retailer grading to meet the specific requirements of the trade.

*Food and Agriculture Organization of the United Nations.

Where grading rules have been established for a species or group of species, they are usually published in booklet form by the lumber associations and are available on request. Space does not permit including such rules herein.

The following trade organizations in Canada publish lumber grading rules:—

British Columbia Lumber Manufacturers' Association, Vancouver, B.C.

Domestic and export rules for Douglas fir, western hemlock, Sitka spruce, and western red cedar lumber are published by this Association. Other rules in use in British Columbia for these species include those issued by the West Coast Lumbermen's Association of Portland, Oregon, governing shipments to the United States, and the Pacific Lumber Inspection Bureau, for export by water.

Canadian Lumbermen's Association, Ottawa, Ont.

This Association has its own rules for grading white pine and red or Norway pine. In addition, it has adopted the grading rules for eastern spruce and balsam fir published by the Northeastern Lumber Manufacturers' Association, New York, and the rules for the measurement and inspection of hardwood lumber published by the National Hardwood Lumber Association, Chicago.

Maritime Lumber Bureau, Amherst, N.S.

This Bureau issues its own rules for the grading of eastern spruce and balsam fir.

Other Rules

In addition, rules of the Western Pine Association, Portland, Oregon, are used in Canada for the grading of the pines, spruces, and other softwood species manufactured in the region between the British Columbia Coast and Eastern Canada.

DEFINITIONS OF SOME TERMS USED IN THE LUMBER INDUSTRY

ADZING MACHINE (ties).—A machine used for bringing into the same plane, by surfacing, those portions of the upper face of a tie on which the rails or rail-plates rest.

AIR-DRY.—The condition reached by lumber seasoned under natural atmospheric conditions.

ALLIGATOR.—A boat used in handling floating logs; it can be moved overland from one body of water to another by means of a winch on board attached by a cable to an anchor fixed in advance by an auxiliary boat or otherwise.

ANNUAL GROWTH RING.—The ring seen on the transverse section of a piece of wood, caused by contrasting spring-wood and summer-wood and denoting one year's growth of wood.

ARCHITRAVE (door, etc.).—The group of mouldings above and on both sides of a door or other opening.

BAND-SAW.—An endless, belt-like, steel saw, running on two wheels; the saw may be toothed on one or both edges.

BARN BOARDS.—Boards of good width used for barn siding.

BASEBOARD.—Interior trim used on the wall of a room along the floor.

BATTEN.—A thin, narrow piece of lumber used for covering panel or siding edges; also pieces used at sides, top, or bottom as reinforcements in constructing boxes and crates. In some markets the term is applied to square-edged pieces 2 inches to 4 inches thick and 5 to 8 inches wide. Slating battens are one-half to 1¼ inches thick and 1 to 3½ inches wide.

BEAD.—A small moulding, semi-circular in section. A "cock" bead is one raised above the surface; a "flush" bead is one level with the surface; a "sunk" bead is one below the surface. Several beads side by side are called "reeds".

BEAM.—A structural timber supported at two or more points, but not throughout its full length, and carrying a transverse load.

BEVEL SIDING.—Boards 4 to 12 inches in width, tapering to a thin edge, and used as covering for sides of buildings.

BILGE SAW.—A cylinder saw used for cutting small cooperage stock.

BILLET.—A short portion of a log, or a roughly shaped piece of wood from which a finished article is to be manufactured.

BIRD'S-EYE.—A series of conical depressions in the growth-rings which, on a flat-sawn surface, appear as small markings of nearly circular outline resembling a bird's eye.

BIRD-PECK.—A small hole or patch of distorted grain resulting from birds pecking through the growing cells in the tree.

BLANK.—A piece of wood cut to a size from which the manufactured article is finished.

BLEEDING.—An exudation of resin, gum, creosote, or other substance from lumber.

BLEMISH.—Anything marring the appearance of wood.

BLOWER KILN.—see Kiln.

BLUE-STAIN.—see Stain, Blue.

BOARD.—A piece of sawn lumber up to and including 1½ inches in thickness and 4 inches and up in width. In certain countries the term is applied to lumber 2 inches and under in thickness, 4 inches and over in width.

BOARD FOOT.—see Section on "Standards of Measurement".

BOARD MEASURE.—see Section on "Standards of Measurement".

BOLE.—The trunk or stem of a tree, large enough for conversion into timber.

BOOM.—A number of floating logs enclosed by heavy timbers or logs fastened end to end and called boom-sticks.

BOWING.—The curving of a piece of lumber flatwise in the direction of its length.

BOX BOARDS.—Lumber for box manufacture; in grading rules for certain species, the name of a distinct grade.

BOX SHOOK.—Lumber cut to size for box manufacture, ready for nailing.

BOX THE HEART.—The method of sawing a log so as to leave the pith completely enclosed in one piece of lumber; such pieces are known in the trade as "boxed heart".

BRASH.—A condition in wood marked by breakage with a short fracture, i.e., little splintering; it indicates low resistance to impact.

BREAK DOWN.—To saw a log into cants.

BRIDGING.—Pieces of wood placed between beams or joists to prevent lateral movement.

BRIGHT.—A term used to denote the absence of weathering effects. As applied to sapwood, it often denotes the absence of stain.

BROADS.—Deals over 11 inches in width.

BROWN STAIN.—see Stain, Brown.

BULL CHAIN.—An endless chain used for conveying logs from the mill pond to the mill.

BURL.—An excrescence on a tree produced by a cluster of knots or by the healing of a wound.

BUTT.—The larger end of a log, or the base of a tree.

CAMBIUM.—The layer of tissue just beneath the bark of the tree from which the new wood and bark cells of each year's growth develop.

CANT.—A log slabbed on two sides only. Synonymous with "flitch", q.v.

CARCASS.—The structural timber work of a building before finishing is added; also the main framework of cupboards, book-cases, chests of drawers, counters, etc.

CASE-HARDENING.—A defect produced through faulty drying of lumber, owing to the exterior drying out while the interior of the piece is still moist.

CASING.—Lumber used as interior trim around window and door frames.

CEILING.—Matched lumber, normally with V-joint pattern, used for ceiling and wainscoting.

CHECK.—A longitudinal crack in timber, generally caused by faulty seasoning.

CHIMNEY.—An opening in the centre of a lumber pile, top to bottom, to facilitate circulation of air.

CLAPBOARD.—A board which tapers to a thin edge, used for exteriors of walls.

CLEAR.—Lumber almost completely free from blemishes or defects.

CLEAT.—A piece of wood used for reinforcing the ends in box construction; a piece placed on the ends of planks or timbers to prevent checking while seasoning.

COARSE.—As applied to the grain of lumber, that which has unusually wide growth rings for the species.

COLLAPSE.—An irregular drawing together or breakdown of the cell walls in wood as free moisture leaves the cavities during drying. It occurs in the early stages of drying wet heartwood, and results in a caved-in or corrugated appearance in the piece.

COMMON.—A term applied to a grade of lumber containing numerous defects which render it unsuitable for high-class finish, but suitable for general construction.

COMPRESSION-WOOD.—Abnormally dense wood which may form on the lower side of branches and of leaning trunks of softwood trees. It has the appearance of heavy summerwood with relatively wide annual rings, usually eccentric. It shrinks excessively lengthwise as compared with normal wood.

CONCAVE SAW.—A circular saw having a curved cross-section and used to produce curved stock for chairs, cooperage, vehicles, etc.

CORD.—A pile of wood occupying a space of 128 cubic feet.

CORE.—The base of veneered work, or the piece or pieces between the surface layers in plywood; the piece remaining after a log has been cut into veneer by the rotary process.

CORNICE.—A projecting horizontal moulding at the top of a pedestal, door, window, or building.

CRIB.—A raft of logs or square timber fastened together, generally for towing. Usually refers to a small raft which, with others of its kind, makes up a full raft.

CROOK (side-bending).—A deviation edgeways from a straight line drawn from end to end of a piece of lumber.

CROSS BAND.—The layer of veneer at right angles to the face plies; to place layers of wood with their grains at right angles, to minimize warping.

CROSS-CUT.—To cut at right angles to the grain of a log or piece of lumber.

CROSS-GRAIN.—Denotes that the fibres do not run parallel to the face and edge.

CROSSER.—A piece of lumber separating the different courses or layers in a lumber pile, with particular reference to piling for air-seasoning (also called "Sticker").

CULL.—As applied to lumber, denotes material below any recognized grade; as applied to logs, denotes those rejected, or portions of logs deducted in scaling. In certain places "culling" is a term applied to the measuring of timber.

CUP OR CUPPING.—A curve across the grain or width of a piece.

CURL.—The figure produced in wood when sawn at the junction of a branch and the stem, or of two branches.

CURLY GRAIN.—Wood is said to be curly-grained when the grain is undulating without crossing. When these undulations are large, the grain is said to be "wavy".

CUT.—The output of logs or lumber for a given period of time.

CUTS.—A grading term used where the piece is to be cut up for further manufacture, as distinguished from other lumber which is intended for use as a piece.

DEADHEAD.—A partly sunken log. In shallow water, a log with one end on the bottom and one afloat; in deep water, a log with just enough buoyancy to keep one end afloat.

DEAL.—A piece of square-edged softwood usually 2 inches to 4 inches in thickness, 9 inches to 11 inches in width, and 8 feet and up in length. Deals wider than 11 inches are called "Broads" or "Broad Deals," and those under 8 feet in length "Deal ends" and "Deal butts", according to the length.

DECAY.—The disintegration (usually called "rot") of wood by fungi.

DEFECT.—A fault or irregularity in lumber which detracts from the utility, durability, strength, or appearance of a piece.

DE-GRADE.—A lowering of the grade of lumber resulting generally from seasoning or manufacturing defects.

DIAMONDING.—A distortion in drying which causes a piece of wood, rectangular in cross-section, to become diamond-shaped on account of the difference between the radial and the tangential shrinkage.

DIMENSION STOCK.—Squares or flat stock, rough or dressed, green or dry, cut to the approximate dimensions required by wood-working factories.

DOTE.—Decay.

DOVETAIL.—Tenon shaped like dove's spread tail, fitting into corresponding mortise to form a joint.

DOWEL.—A cylindrical wooden pin used for holding two pieces of wood together.

DOZY.—Synonymous with "Doty", i.e., showing advanced decay.

DRESS.—To plane one or more sides of a piece of sawn lumber.

DRIVE.—A body of logs in process of being floated from the forest to the sawmill or shipping point; the act of transporting logs by floating them.

DROP SIDING.—A pattern of lumber used to cover the exterior of buildings.

DRY-KILN.—see Kiln.

DRY-ROT.—Decay caused by certain fungi, which are peculiarly adapted in regard to supplying their own moisture requirements. The fungi always commence growth in moist wood, but are later enabled to spread to dry wood, owing to the development of special water-conducting organs. The term is often loosely applied to any dry, crumbly rot.

DURABILITY.—A general term referring to the resistance of a species, or of the wood thereof, to attack by wood-destroying fungi.

EASED-EDGE.—A piece of wood slightly rounded or bull-nosed on each edge.

EAVE.—That part of a roof which projects beyond the face of a wall.

EDGE.—The narrow face of a rectangular piece of lumber.

EDGE-GRAIN.—Lumber that is sawn along a radius of the annual rings or at an angle less than 45° to the radius is edge-grained; this term is synonymous with quarter-sawn.

EDGINGS.—The waste strips cut from the edges of lumber.

END GRAIN.—Grain of the transverse section of a log or piece of lumber.

END-MATCH.—To tongue-and-groove the ends of lumber.

EQUILIBRIUM MOISTURE CONTENT.—The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

EXCELSIOR.—Long, narrow, curling, wood shavings used for packing material; also called wood-wool.

FACE SIDE.—That side of a piece which shows the best quality.

FACINGS.—Dressed boards, with or without mouldings, used in exposed places.

FACTORY LUMBER.—see Lumber.

FATHOM.—A cubic measure used in Great Britain for pit-props, etc.; it contains 216 cubic feet of stacked wood.

FEATHER EDGE.—A board which is thinner on one edge than the other is said to be "feather-edged".

FIBRE-SATURATION POINT.—The stage in the drying of wood when all the free water has been driven off, leaving the cell walls saturated; the moisture content below which lumber begins to shrink.

FIGURE.—The pattern produced in a wood surface by irregular coloration, annual growth rings, knots, or deviations from normal grain.

FINE-GRAIN.—Having narrow annual rings.

FINISH.—As applied to lumber grades, this term refers to the upper grades suitable for natural or stained finishes.

FLAT-GRAIN.—Plain-sawn or sawn tangential to the annual rings, as opposed to edge-grain or quarter-sawn.

FLECKS.—Spots, dapples, or marks caused by local irregularities in the grain.

FLITCH.—A thick piece of timber, either hewn or sawn, frequently with wane on one or both edges, and intended for further manufacture.

FLUTES.—Hollows or grooves cut longitudinally for ornamental purposes.

FRETWORK.—Thin wood in which a pattern or design has been produced by cutting out portions of the material by means of a very thin saw mounted in a frame, and known as a fret-saw.

FURRING.—Any flat piece of lumber used to bring an irregular framing to a flat surface; in particular, a narrow strip of 1-inch lumber which is nailed to rafters, studding, and joists as a backing for lath.

GANG-MILL.—A wood-sawing machine in which several saws, usually of the reciprocating type, cut simultaneously.

GANG-SAW.—A ribbon of steel toothed on one edge and cutting only on the downward stroke; a number of these are stretched in a frame to form a gang-mill.

GIRDER.—A principal horizontal beam, or a compound structure acting as a beam, carrying a vertical load and bearing vertically upon its supports.

GRADE.—A term to denote the quality or classification of lumber in relation to its adaptability for different uses: also the procedure of separating lumber into different established classes or grades.

GRAIN.—A term used with reference to the arrangement or direction of the wood elements (spiral grain, cross-grain, etc.) and to the relative width of the growth-rings (coarse-grain, fine-grain, etc.). It is also used to designate the angle of the growth rings in relation to the axis of the board (edge-grain, flat-grain).

GREEN LUMBER.—Unseasoned or wet lumber; lumber in which free water still remains within the cells; lumber which has a moisture content above the fibre-saturation point (approximately 25 to 30 per cent).

GROWTH RING.—see Rings, annual growth.

GUM VEIN.—A local accumulation of gum found in certain hardwoods and occurring in the form of a vein.

HARDWOOD.—Conventional term used to denote the timber of broad-leaved trees belonging to the botanical class of Angiosperms.

HEADING.—Stock from which the tops and bottoms of barrels or other similar containers are cut; also the finished articles.

HEADSAW.—The principal saw used for breaking down the log.

HEARTWOOD.—The inner layers of wood which in the growing tree have ceased to contain living cells, as opposed to the sapwood, which contains growing cells. Heartwood is generally darker in colour than sapwood, though in some species the difference is scarcely perceptible.

HEWN.—Cut with an axe or an adze.

HOG.—A machine used for converting wood into fuel chips.

HOLLOW-BACKED.—A board in which one or more grooves have been cut from the central part on one side is called hollow-backed.

HONEYCOMBING.—The development of interior checks in wood in the course of seasoning.

HOUSING.—A groove or trench in a piece of wood made for the insertion of a second piece.

INCISING.—An operation on railway ties and other timbers preparatory to preservative treatment. Small longitudinal incisions are made on the sides and edges to facilitate deeper and more uniform penetration of the preservative.

INTERIOR TRIM.—Worked lumber used for finishing the interiors of buildings.

INTERLOCKING GRAIN.—Wood in which the fibres are inclined in one direction in a number of annual growth-rings, then gradually reversed and inclined in the opposite direction in succeeding growth-rings, then reversed again, etc.

INTERNAL SAPWOOD.—A zone of wood within the heartwood that retains the light colour of the sapwood.

JACK LADDER.—A device by which logs are conveyed from the pond to the mill.

JAMB.—The side of a window, door, or other such opening.

JOINERY.—The fitting and joining together of pieces of wood into a finished wooden article or structure. It refers to "fine carpentry", "bench carpentry", and similar forms of fine woodworking, but not to cabinet-work or pattern-making.

JOIST.—A piece of dimension or structural timber used to support the floor boards or the ceilings of a building.

KERF.—The groove formed in wood while being sawn or the thickness of the wood removed as sawdust.

KILN.—A heated chamber for drying lumber.

KILN-DRIED LUMBER.—Lumber which has been seasoned in a dry-kiln, usually, though not necessarily, to a lower moisture content than that of air-seasoned lumber.

KNEE.—A piece of timber formed with an angle in the shape of the human knee when bent, usually cut from a crotch or root of a tree; also that portion of a sawmill carriage head-block which bears the carriage-dogs.

KNOT.—That portion of a branch or limb embedded in the tree and cut through in the process of lumber manufacture. Knots are classified according to size, form, quality, and occurrence. As regards size, a *pin* knot is one not over one-half inch in diameter; a *small* knot is one over one-half inch in diameter but not more than three-quarters of an inch in diameter; a *medium* knot is one over three-quarters of an inch but not over 1½ inches in diameter; a *large* knot is one over 1½ inches in diameter. As to form, a *round* knot is one circular or nearly circular in form; a *spike* knot is one which has been formed by sawing the embedded branch in a lengthwise or nearly lengthwise direction, With reference to quality, a *sound* knot is solid across its face, is as hard as the surrounding wood and shows no indication of decay; an *unsound* knot is solid across its face but contains incipient decay; a *decayed* knot is softer than the surrounding wood and contains advanced decay; a *tight* knot is one so fixed by growth or position that it will firmly retain its place in the piece; an *intergrown* knot is one whose rings of annual growth are partially or completely intergrown with those of the surrounding wood; an *encased* knot is one whose rings of annual growth are not intergrown and homogeneous with those of the surrounding wood (the encasement may be partial or complete and may be composed of either pitch or bark); a *loose* knot is one which is not held firmly in place by growth or position and which cannot be relied on to remain in place in the board; a *pith* knot is one which is sound, with a pith-hole not more than one-quarter inch in diameter; a *hollow* knot is an apparently sound knot with a relatively large hole in it. With regard to occurrence, a *single* knot is one occurring by itself with the fibres of the wood deflected around it; a *knot cluster* is the grouping of two or more knots together as a unit with the fibres of the wood deflected around the entire unit (a group of single knots is not a knot cluster); *branch* knots are two or more knots branching from a common centre.

LAMINATED.—A type of construction in which layers of wood, the grain in all cases running lengthwise of the assembly, are joined by gluing or other means to form a single member.

LAP SIDING.—Boards used to cover the sides of buildings, the lower edge of one board being lapped over the upper edge of the board below.

LATH.—A thin narrow strip of wood nailed to the wall or ceiling as a base for plaster.

LATH BOLT.—A piece of wood from which laths are manufactured.

LOG.—The section of the stem of a tree from which lumber is manufactured.

LOG DECK.—The platform in a sawmill upon which logs are collected previous to being placed on the carriage for sawing.

LOG POND.—see Mill-pond.

LOG RUN.—In softwoods, generally all salable lumber as it comes from the saw; in hardwoods, the full run of the log with all grades below No. 2 Common excluded.

LUMBER.—The product of the saw and planing mill not further manufactured than by sawing, resawing and passing lengthwise through a standard planing machine, cross-cutting to length, and matching.

Yard lumber.—Lumber of all sizes and patterns which is intended for general building purposes.

Factory and shop lumber.—Lumber intended to be cut up for use in further manufacture and graded on the basis of the percentage of the area which will produce cuttings of a given quality and size.

Structural lumber.—Lumber that is 2 or more inches thick and 4 or more inches wide, intended for use in supporting loads.

MARQUETRY.—The art of inlaying wood with wood of other colours, or with various other materials.

MATCHED.—Lumber machined or dressed to any form of joint, e.g., tongue-and-groove; fancy or ornamental wood matched in figure.

MATCHER.—A surfacing machine used in a planing mill for matching lumber.

MEDULLARY RAYS.—Cellular tissues which usually run continuously from the pith to the bark, particularly prominent in quarter-cut oak.

MERCHANTABLE.—In general, denotes timber that is salable. The term is also applied to a specific grade for many species of wood.

MERCHANTABLE LOG.—A log which will produce enough lumber of a quality sufficiently good to make it profitable to transport it to the sawmill for manufacture.

MILL-POND.—A pond in which logs are stored at the sawmill.

MILL RUN.—All the lumber produced in a mill, without reference to grade.

MILLWORK.—Building materials made of finished wood and including such items as inside and outside doors, window and door frames, panel work, mouldings, and interior trim. It does not include flooring, ceiling, or siding.

MOISTURE CONTENT.—The amount of water in wood, generally expressed as a percentage of the oven-dry weight of the wood.

MORTISE.—The cut made in a board to take a tenon.

MOULD.—A superficial fungous growth which usually appears in the form of a woolly or furry coating.

MOULDING.—Lumber which has been worked on its side or edge to a uniform cross-section, other than rectangular, so as to give an ornamental effect.

NIGGER.—Also called "Steam Nigger". A long, toothed lever, steam-driven, used to turn logs on a sawmill carriage.

NOMINAL MEASURE.—In worked lumber, the dimensions of the rough board before dressing.

NOSING.—Edge of a board worked into the form of a semi-circle.

ODD LENGTHS.—A term applied to lumber whose length dimensions are in odd feet.

OVEN-DRY.—The term applied to wood which does not continue to lose moisture after an interval of time in an oven at 100° Centigrade.

OVERHANG.—The forward pitch given to the front of a pile of lumber for protection against sun, rain, etc.; the unsupported ends of long pieces in a pile not box-piled.

OVERRUN.—The difference between the mill cut of timber and that estimated from the log scale, generally calculated as a percentage of the log scale.

PANEL.—A piece of board or plywood framed within four other pieces of wood.

PARQUET.—Flooring laid in geometrical designs with small pieces of wood.

PARTITION.—A pattern of lumber for such work as partitions, where both sides of the lumber are exposed.

PECK.—An advanced stage of decay involving the formation of pockets or areas of disintegrated wood.

PETROGRAD STANDARD.—Unit of measurement of softwood lumber in Europe, equal to 1,980 feet board measure, or 165 cubic feet.

PITCH.—Accumulation of resin in wood. This accumulation may be in the form of pitch pockets, pitch streaks, or pitch seams.

PITH.—The small, soft core occurring at the centre of a tree or log.

PLYWOOD.—A piece of wood made of two or more layers of veneer joined with glue and usually laid with the grain of adjoining plies at right angles. To secure balanced construction, it is customary for an odd number of plies to be used.

PRESERVATIVE.—Any substance that will, for a reasonable length of time, prevent the action of wood-destroying fungi, borers of various kinds, and similar destructive agents, when the wood has been properly treated.

QUARTER-SAWN, QUARTER-CUT.—Lumber cut in a radial direction, that is, at right angles to the direction of the annual rings. In softwoods it is usually called "edge-grain". "Rift-sawn" is another term for "quarter-sawn".

RABBET.—A longitudinal channel, groove, or recess cut out of the edge or face of any wooden member, especially one intended to receive another member.

RAFT.—A collection of logs or other timbers held together for transportation by floating.

RAFTERS.—Beams supporting sloping roofs.

RAILS.—The horizontal pieces of wood in panelled woodwork such as doors, as opposed to stiles, which are the vertical pieces.

RATE OF GROWTH.—The rate at which a tree has grown wood, measured radially in the trunk of the tree or in lumber cut from the trunk. The unit of measure is the number of annual rings per inch.

REFUSE BURNER.—A structure in which slabs, sawdust, bark, and other mill waste are burned.

RESAW.—A circular saw or band-saw used to saw boards, cants, planks, etc., into thinner lumber; the act of sawing a piece of lumber into two or more thinner pieces.

RIFT-SAWN.—Similar to *Quarter-sawn.*

RINGS, ANNUAL GROWTH.—The growth layer put on in a single growth year and comprising spring-wood and summer-wood.

RIP.—To saw a board lengthwise.

RIVE.—To split.

ROOFERS.—One-inch lumber nailed to rafters as backing for shingles.

ROSSING.—Taking off bark.

ROTARY-CUT VENEER.—Veneer cut by revolving a log against a knife running the length of the log and set in such a manner as to peel off a continuous thin sheet.

ROUGH LUMBER.—Lumber that has not been planed or dressed.

SAPS.—A term sometimes used to refer to hardwood pieces containing all or part sapwood.

SAPWOOD.—The outer layers of the tree, containing living cells. The sapwood is generally lighter in colour than the heartwood.

SASH.—The framed casement part of a window in which the glass is fixed.

SASH FRAME.—The outer frame with sill in which the sliding sashes or casements are suspended.

SAW KERF.—see Kerf.

SCAFFOLDING.—A temporary structure or stage used by workmen in the process of building.

SCANT.—A term used to imply dimensions in sawn lumber slightly under the nominal dimensions.

SCANTLING.—A piece of timber of small size, usually about 2 by 4 inches in cross-section; in certain markets a piece of square-edged timber 2 to 4 inches thick by 2 to 4½ inches wide.

SCOOTS.—Culls from hardwood mill run.

SEASON CHECKS.—Cracks occurring in lumber while seasoning.

SEASONING.—The act of drying lumber, either naturally in the open or artificially in a dry-kiln; the removal of moisture from wood to improve its serviceability.

SECOND GROWTH.—Trees which grow up after the original stand has been cut over, burned, or otherwise removed.

SECRET NAILING.—Nailing boards in such a manner that the nail heads are not seen.

SELECTS.—In general, a word used in the lumber industry to imply upper grades; for certain species, particularly hardwoods, it refers to a specific grade.

SHAKE.—A shingle split (not sawn) from a bolt of wood and used for roofing and siding, or a shingle manufactured in imitation of the above.

SHAKES.—Defects originating in the living tree due to frost, wind, or other causes, or occurring through injury in felling, driving, etc., which later show in the manufactured lumber, most commonly as partial or complete separation between growth-rings. *Ring shake* is a separation between adjoining growth-rings; *transverse shake*, a separation running across the fibres; *through shake*, one extending from one surface through the piece to the opposite surface or to an adjoining surface.

SHEATHING.—Lumber used to cover the framework of buildings.

SHINGLE.—A thin rectangular piece of wood tapering in thickness with the grain to facilitate overlapping of the shingles in covering roofs and exterior walls.

SHINGLE BOLT.—A short, split section of a log from which shingles are manufactured.

SHIPLAP.—A pattern of lumber in which one-half the thickness of the board is cut from the upper side of one edge, and a similar section from the lower side of the opposite edge.

SHIPPING DRY.—Shipping lumber with the moisture content in equilibrium with the surrounding atmospheric conditions; shipping lumber sufficiently seasoned to prevent fungous attack in transit.

SHOOK.—see Box Shook.

SHOP —see Lumber.

SHORTS.—Lumber shorter than standard lengths.

SIDING.—Lumber used as the finish covering of exterior walls.

SILL.—A piece of wood used to support a door or window, or placed on a masonry or other foundation as a base for the framework of a building, or which is used for other similar purposes of support.

SILVER GRAIN.—Conspicuous medullary rays in quarter-sawn lumber.

SKID.—The hauling of logs from the falling-ground to storage piles or skidways; also the timbers on which the logs are moved or stored.

SKIDWAY.—A roll-way on to which logs are rolled and piled for storage in bush operations.

SKIPS IN DRESSING.—In surfacing lumber, slight depressions which are below the plane of the cut and therefore remain in a rough condition.

SLAB.—Exterior portion of a log which is removed in sawing lumber.

SLACK COOPERAGE.—Barrels, kegs, etc., for non-liquid materials.

SLASH GRAIN.—Synonymous with *Plain-sawn*, *Flat-grain*.

SLASHER.—Several circular saws mounted on a shaft at intervals of from 16 to 48 inches and used to cut slabs, edgings, and other wood refuse into lengths suitable for laths, firewood, or pulpwood, or for transportation to the refuse burner.

SLAT.—A term loosely applied to pieces of narrow lumber, as in bed slats. Applied to pencil manufacture, a slat is a sawn piece of wood about 7¼ inches by 2½ inches by one-quarter inch.

SLATING BATTENS.—Small strips of wood to which roofing slates are fastened.

SLEEPERS.—Railway ties.

SOFTWOOD.—The timber of trees belonging to the botanical group of Gymnosperms, i.e., conifers, or evergreens.

SORTING BOOM.—A boom used in guiding logs into the sorting jack.

SORTING JACK.—A fixed raft, through an opening in which logs pass to be sorted and diverted into pocket booms or into the downstream channel.

SORTING TABLE.—A long platform in a sawmill on which lumber is sorted into different grades or sizes.

SPIRAL GRAIN.—An arrangement of the fibres in which they follow a consistently curved course or spiral direction around the bole of the tree.

SPLINE.—A rectangular strip of wood which is substituted for the tongue on heavy factory flooring and for other similar purposes.

SPOOLWOOD.—Small sawn squares, usually of the hardwoods of medium hardness, from which spools are turned.

SPRING-WOOD.—The inner part of the annual ring, which grows in the early part of the year; usually lighter in colour and weight than the remainder of the ring.

SQUARE.—100 square feet; a unit of measurement for shingles. In certain markets it is used for flooring, and for matched and other worked lumber.

SQUARE-EDGED.—Sawn lumber without wane.

STACKER.—A machine for loading lumber on trucks and lumber piles.

STAIN, BLUE.—A bluish discoloration, caused by certain fungi, which seldom penetrates beyond the sapwood.

STAIN, BROWN.—A dark, often chocolate brown, discoloration found in the sapwood of some softwoods stored under unfavourable seasoning conditions; it is caused by a fungus.

STAIN, CHEMICAL BROWN.—A dark brown discoloration, usually confined to the heartwood, which may develop during air-seasoning or kiln-drying.

STAIN, SAP.—see Stain, Blue.

STAND.—All growing trees in the forest.

STANDARD.—see section "Standards of Measurement".

STAVES.—Narrow pieces of wood from which the sides of barrels, casks, tubs, etc., are made.

STEPPING.—Lumber worked to a size and pattern suitable for steps.

STICKER.—A piece of lumber separating the different courses or layers in a lumber pile; a machine used in a sash and door factory for shaping rails, stiles, sash bars, etc. (also see Crosser).

STILE.—A vertical piece of a sash, door, or piece of framing to which the rails are attached.

STRAIGHT GRAIN.—Implies that the direction of the principal fibres is parallel to the axis of the tree or log. A board is straight-grained when these fibres are parallel to its length.

STRIP.—A term somewhat loosely used for several purposes, but generally implying a narrow board, e.g., flooring strip. In certain species it refers to a definite grade of narrow lumber of good quality.

STRUCTURAL TIMBER.—Timber to be used in construction to bear loads, and therefore graded on the basis of the suitability of the entire piece for that purpose.

STUDDING.—Implies the use of scantlings or studs (see "Scantling").

SUMMER-WOOD.—The outer section of the annual ring, which develops in the late summer. It is usually darker and heavier than the inner portion or spring-wood.

SURFACE OR SUPERFICIAL MEASURE.—see Section on "Standards of Measurement".

SURFACED LUMBER.—Lumber that has been dressed or planed by running it through a planing machine (also see "Rough" and "Worked" Lumber).

SWING SAW.—A circular cut-off saw suspended by its frame on a shaft, the saw being pulled forward when cutting.

TENON.—The end of a piece of lumber formed to fit into a mortise.

TEXTURE.—The distribution and relative size of the wood elements; as in coarse texture, fine texture, even texture, close texture.

TIGHT COOPERAGE.—Containers of the barrel type composed of staves and round headings held solidly together with hoops and intended to hold liquids.

TIMBER.—Standing trees of commercial size; felled trees or logs suitable for sawing; as applied to manufactured wood, sawn or hewn wood 4 inches or over in thickness and 4 inches or over in width.

TONGUE.—A projection on the edge of a board machined to fit into a groove in the adjacent piece.

TORN GRAIN.—A machine defect on surfaced lumber consisting of the tearing out of the fibres by the planer knives, generally around knots or other irregularities.

TRIM.—Worked lumber used in finishing the interiors and exteriors of buildings; to make square the ends of boards and timbers.

UNDERCUT.—In felling timber, the notch cut in the tree to determine the direction of fall and to prevent splitting.

UNDERWEIGHTS.—A word used to denote the difference between the standard shipping weights of shingles and lumber and the actual shipping weights.

VENEER.—A thin piece or layer of wood of uniform thickness cut on a veneer machine, and either sawn, sliced, or rotary-cut.

VERTICAL-GRAINED.—Synonymous with *Quarter-sawn.*

WAINSCOT.—Wooden panelling or boarding on a room wall.

WALINGS.—Horizontal timbers used as guides in driving sheet piles; also refers to a timber used as a strap or brace.

WANE.—As opposed to square-edged material, wane denotes the absence of wood on the edge of sawn or hewn timber and the presence of bark or a sapwood surface from which bark has fallen.

WARP.—Any variation from a true surface, such as bow, cup, twist, etc., often caused by defective seasoning.

WAVY GRAIN.—see Curly Grain.

WEATHER-BOARD.—A term sometimes applied to overlapping lumber used for siding, such as bevel siding, clap-boards, etc.

WOOD-WOOL.—see Excelsior.

WORKED LUMBER.—Lumber that has been run through a matching machine, sticker, or moulder. It may be *matched*, i.e., with tongue and groove joint at the edges, *shiplapped*, i.e., with a close rabbetted or lapped joint at the edges or *patterned*, i.e., shaped to a patterned or moulded form. (Also see Rough and Surfaced Lumber.)

YARD LUMBER.—see Lumber.

LUMBER TRADE ABBREVIATIONS

A D. . . . . Air-dried
A.G. . . . . Angle grain
a.l. (AL) . . . . All lengths
av.l . . . . Average length
av.w . . . . Average widths
a.w. . . . . All widths
B & CB . . . . Beaded and centre-beaded
B & CB2S . . . . Beaded and centre beaded two sides
B1S. . . . . Beaded one side
B2S. . . . . Beaded two sides
BBS. . . . . Box bark strips
bd. ft. *or* b.f. . . . . . . Board foot (12 x 12 inches by 1 inch thick)
bdl . . . . Bundle
bdl. bk.s. . . . . Bundles barked strips
Bev. . . . . Bevelled
B. Clg . . . . Beaded ceiling
B/L . . . . Bill of lading
b.m. (sometimes B.M.) . . . . Board measure
Btr . . . . Better
CB . . . . Centre beaded
Clg . . . . Ceiling
Clr . . . . Clear
Cm . . . . Centre-matched; tongue and groove worked on centre of the edges of the piece.
Com. . . . . Common
Coop. . . . . Cooperage stock
Csg. . . . . Casing
Ctg. . . . . Crating
Cust. . . . . Custom-sawn
*D & CM . . . . . . Dressed, one or two sides, and centre matched.
*D & H . . . . Dressed and headed; dressed on one or two sides and worked to tongue and groove joints on both the edge and the ends.
*D & M . . . . Dressed and matched; dressed one or two sides and tongued and grooved on edges, whether in centre or standard.
*D & SM . . . . Dressed, one or two sides, and standard-matched.
*D2S & CM . . . . . Dressed two sides and centre-matched.
*D2S & M . . . . . . Dressed two sides and matched (centre or standard).
*D2S & SM . . . . . Dressed two sides and standard-matched
*D4S . . . . Dressed four sides
Dim . . . . Dimension
Dr. . . . . Door
D.S. . . . . Drop siding
E . . . . Edge
E & CB1S . . . . Edge and centre bead one side; surfaced one or two sides and with a longitudinal edge and centre bead on a surfaced face.
E & CB2S . . . . Edge and centre bead two sides, all four sides surfaced and with a longitudinal edge and centre bead on the two faces.

*For these items see also S&CM, S&H, S&SM, etc.

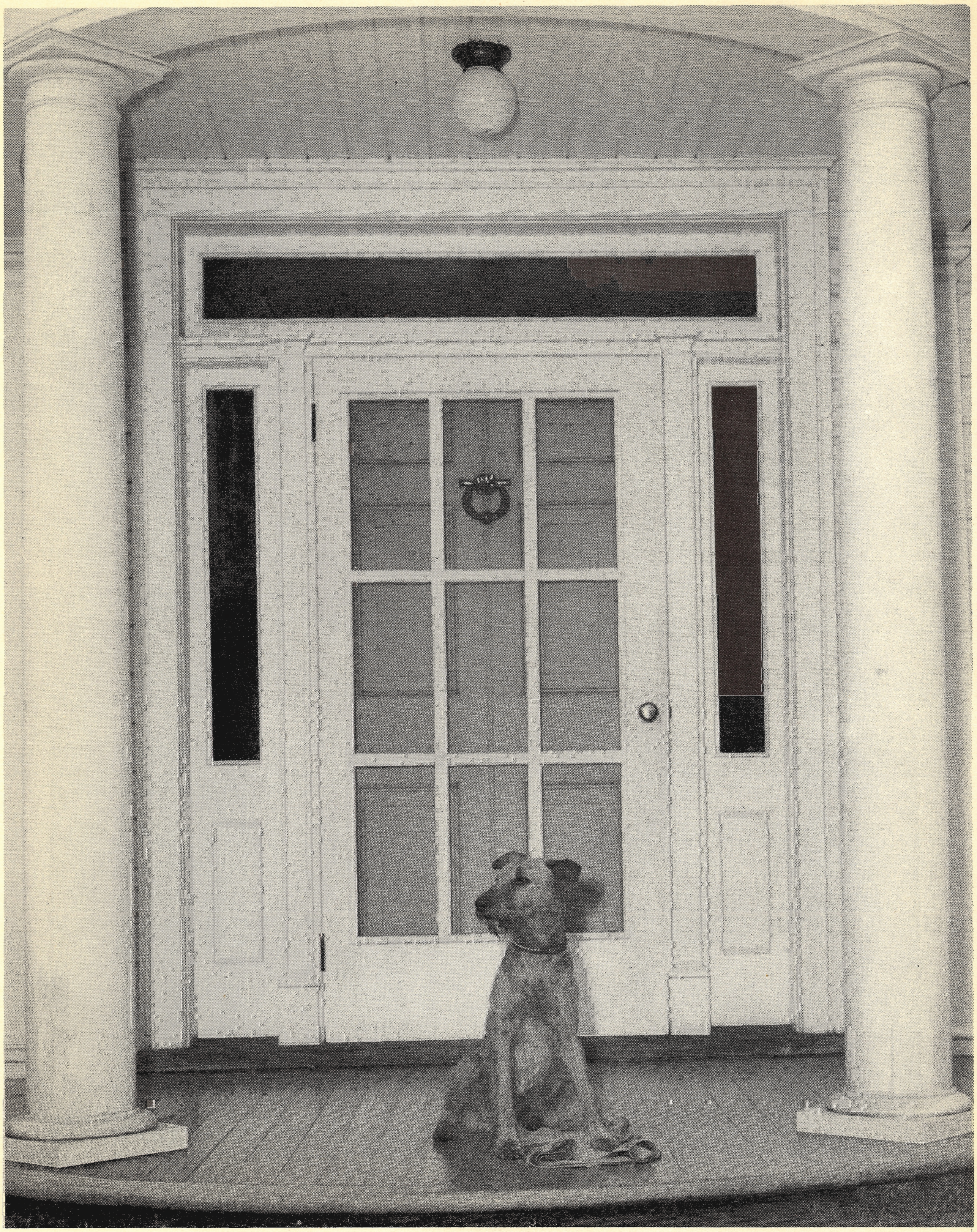
ECM	Ends centre-matched
E & CV1S	Edge and centre V one side; surfaced one or two sides and with a longitudinal edge and centre V-shaped groove on a surfaced face
E & CV2S	Edge and centre V two sides; all four sides surfaced and with a longitudinal edge and centre V-shaped groove on each of the two faces
E.D.	Equivalent defects
E.D.E.C.D.	Equivalent defects or equivalent combination of defects
EE	Eased edges
E.G.	Edge-grain
EM	End-matched, either centre or standard
ESM	End-standard-matched
FAS	First and seconds; combination of the two top grades in hardwoods
f. bk	Flat back
fcty	Factory lumber
F.G.	Flat or slash grain
Flg	Flooring
f.o.k.	Free of knots
f.o.w.	First open water
Frm	Framing
ft.b.m. (or f.b.m.)	Feet board measure
ft.s.m.	Feet surface measure
FURN	Furniture stock
G. (or GR)	Green
G.R.	Grooved roofing
G.T.	Grain tight
H.bk	Hollow back
Hdl	Handle stock
hdwd	Hardwood
H a M	Hit and Miss
Hrt	Heart
Hrtwd	Heartwood
Impl.	Implement stock
KD	Kiln-dried
k.d.	Knocked down
l.c.l.	Less than carload lots
lgr	Longer
lin. ft.	Linear foot
Lng	Lining
LR	Log run
LR, MCO	Log run, mill culls out
Lth	Lath
M	Thousand
M b.m. *or* M ft.b.m.	Thousand feet board measure
MCO	Mill culls out
Merch.	Merchantable
m.l.	Mixed lengths
Mldg	Moulding
MR	Mill run
M.s.m.	Thousand feet surface measure
m.w.	Mixed widths
P	Planed
Pat.	Pattern
Pky	Pecky
Pln sawn	Plain sawn
Pn	Partition
Qtd	Quartered (hardwoods)
rdm	Random
res.	Resawn
Rfg	Roofing
Rfrs	Roofers
Rgh	Rough
rip.	Ripped
r.l.	Random lengths
rnd	Round
R/S	Resawn
R.Sdg.	Rustic siding
r.w.	Random widths
S & E	Surfaced and edged
S1E	Surfaced one edge
S2E	Surfaced two edges
S1S	Surfaced one side
S2S	Surfaced two sides
S1S1E	Surfaced one side and one edge
S2S1E	Surfaced two sides and one edge
S1S2E	Surfaced one side and two edges
S4S	Surfaced four sides
S4SCS	Surfaced four sides with a caulking seam on each edge
S & CM	Surfaced (one or two sides) and centre-matched
S & M	Surfaced and matched. Surfaced one or two sides and tongued and grooved on the edges, either standard or centre matching
S & SM	Surfaced one or two sides and standard-matched
S2S & CM	Surfaced two sides and centre-matched

S2S & SM....... Surfaced two sides and standard-matched
Sap............. Sapwood
SB.............. Standard bead
Sd.............. Seasoned
Sdg............. Siding
Sel.............. Select
S.E.Sdg......... Square-edge siding
s.f............... Surface foot, i.e., one square foot
Sftwd........... Softwood
S.G.............. Slash grain
Sh.D............ Shipping dry
Ship............. Shipment or shipments
Shlp............. Shiplap
s.m.............. Surface measure
SM.............. Standard-matched
s.n.d............ Sap no defect
snd.............. Sound
sq................ Square
Sq. E & S....... Square-edged and sound
sqrs............. Squares
Spf'd G......... Specified grain
Std.............. Standard
stnd............. Stained
stk............... Stock
Stp.............. Stepping
S.W............. Sound wormy

Symbols:

″.............. inch or inches, as 12″
′.............. foot or feet, as 12′
×.............. by, as in 6 × 8 timber
4/4, 5/4, 6/4, 8/4, etc...... 1 inch, 1¼ inches, 1½ inches, 2 inches, etc., when referring to the thickness of lumber
T & G.......... Tongue and groove
TB & S......... Top, bottom, and sides
Tbrs............ Timbers
V1S............ V one side; a longitudinal V-shaped groove on one face of a piece
V2S............ V two sides; a longitudinal V-shaped groove on two faces of a piece
V & CB......... V and centre bead
V & CV......... V and centre V
V.G............. Vertical grain
V.J.Clg......... V-joint ceiling
w.a.l........... Wider, all lengths
Wth............ Width
wdr............ Wider
Wgn........... Wagon stock
W.T............ Water-tight

Mediaeval Timber-frame Construction. Note what little basic change has taken place in methods and tools. (Woodcut by Hans Weiditz, 1531.)



Typical White Pine Construction in Domestic Architecture. (Main entrance of the Kingsmere, Que., residence of the late Rt. Hon. William Lyon Mackenzie King, O.M.)

COMMERCIAL TIMBERS OF CANADA

by T. A. McELHANNEY

IN BULLETIN 61 of the Forest Service, entitled *Native Trees of Canada* (revised edition, 1949), are listed and described 171 Canadian woods. Of these, 35 are coniferous (softwood) species and 136 broad-leaved (hardwood) species, Quite a large number of these occur in small sizes, in limited quantities, or in inaccessible regions, and, while of interest from a botanical standpoint or for ornamental or other restricted purposes, are not of importance from a commercial standpoint. Following is a brief description of the principal species native to Canada which occur in sufficient quantity and have such properties as to make them of value commercially for domestic use. Only about 20 of these are of importance in external trade.

For convenience of reference the species have been divided into two groups, softwoods and hardwoods. Following a brief description of each species there is a list of uses. These are intended only to indicate the properties of a species, by giving typical uses for which industrial practice has shown it to be suitable. More detailed information on the properties of different species appears in tabulated form in other parts of this book. Weights of the various species of wood given in this chapter are those generally accepted commercially.

SOFTWOODS (Conifers)

EASTERN WHITE CEDAR

Thuja occidentalis L.

This species is sometimes referred to as eastern cedar or northern white cedar. It is found in all the eastern provinces, though not in the more northerly portions of Ontario and Quebec, and extends westerly to eastern Manitoba.

It occasionally reaches a height of 80 feet and a diameter at breast-height of 3 feet, but it is generally a comparatively small tree about 1 foot in diameter and 45 feet in height. It is usually found in low swampy ground, but also occurs on limestone ridges with shallow soil.

The wood of white cedar has a pleasant odour. The heartwood is light brown, but the sapwood is very light in colour. The wood is very light in weight —about 21 pounds per cubic foot air-dry. It is comparatively weak and soft, has a fine, even texture, and splits readily. It has very low shrinkage factors, and good working qualities. It is one of the most durable woods in Canada and is particularly desirable for uses in contact with the soil or in other situations favouring decay.

Typical Uses

Shingles	Garden furniture
Boats and canoes	Fence-posts
Cisterns	Tanks
Hothouses	Pontoon floats
Fish-net floats	
Telegraph and telephone poles	
Clothes chests and closets	

WESTERN RED CEDAR

Thuja plicata Donn.

Western red cedar is also called western cedar, red cedar, British Columbia cedar, and giant cedar. It is the largest cedar native to North America, occasionally attaining a diameter of 15 feet or over and a height of 200 feet. In the forest it is generally from 3 to 8 feet in diameter and from 125 to 175 feet

in height; the trunk tapers rapidly. It is found throughout the coastal district of British Columbia and in some of the valleys of the interior where the precipitation is high, but it reaches its best development on Vancouver Island and the adjacent mainland.

Western red cedar has thin sapwood, which is of a light yellow tinge. The heartwood varies considerably in colour from a pinkish red to a deep, warm brown, the latter shade being generally associated with old trees. The wood is straight-grained and splits readily and uniformly; it is quite soft and light, weighing only about 22 pounds per cubic foot when air-dried.

The wood has exceptionally good working qualities and takes a smooth, satiny finish. It takes stains and paints well and has good gluing properties.

Western red cedar has a very fair degree of strength when used as a round pole, for which purpose it is used extensively, or when used in compression as in a post or column, but is not very strong when used as a beam. It is a very durable wood in contact with the soil or in other positions favouring decay. It is particularly valuable as shingles for roofing, for which purpose it is the most widely used wood in America.

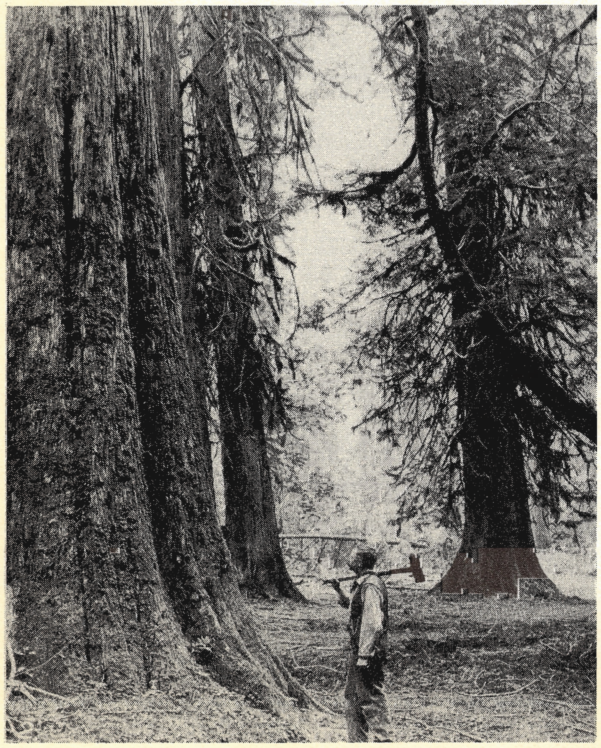


PLATE 1.—Western Red Cedar.

The wood seasons readily with very little shrinkage. This characteristic, combined with its high resistance to changes in moisture content, results in its retaining its size and shape exceptionally well after being properly seasoned. This property has made it much favoured in canoe and boat construction.

Typical Uses

Shingles
Conduits
Boats and canoes
Fish-net floats
Hothouses
Fence-posts
Light construction
Clothes closets and chests
Telegraph and telephone poles
Interior and exterior finish

YELLOW CEDAR

Chamaecyparis nootkatensis (D. Don) Spach

Yellow cedar is sometimes referred to as yellow cypress, Alaska cypress, or Alaska cedar. In Canada, it is found only on the Pacific Coast from Alaska to the southern boundary of British Columbia on the west slope of the Coast Range, and on the adjacent islands. In the southern coastal district, it is generally found growing between 2,000 and 5,000 feet, but farther north it may be found at sea-level.

It is not as large as western red cedar, being commonly about 80 feet tall and 2 to 3 feet in diameter, though it is not infrequently found up to 120 feet in height and 5 to 7 feet in diameter.

The wood is of a pale yellow colour and when freshly cut has a very strong odour, which largely disappears in seasoning: it is fairly hard and strong, has exceptionally fine working qualities, and for this reason is prized for high-class joinery and carving. It has a very low shrinkage factor, and this characteristic, combined with its high durability in situations favouring decay, makes it valuable for windows and exterior doors, the better class of boat construction, and other similar uses. It is also valued for patterns, cabinet-work, and turnery. Its resistance to acids, combined with other properties, has made it the principal Canadian wood used for battery separators. It is highly resistant to teredo attack in sea-water and to the action of termites or other insects. It weighs about 31 pounds per cubic foot, air-dry.

Typical Uses

Battery separators
Hothouses
Cabinet-work
Boats and canoes
Patterns
Drawing boards
Interior and exterior finish

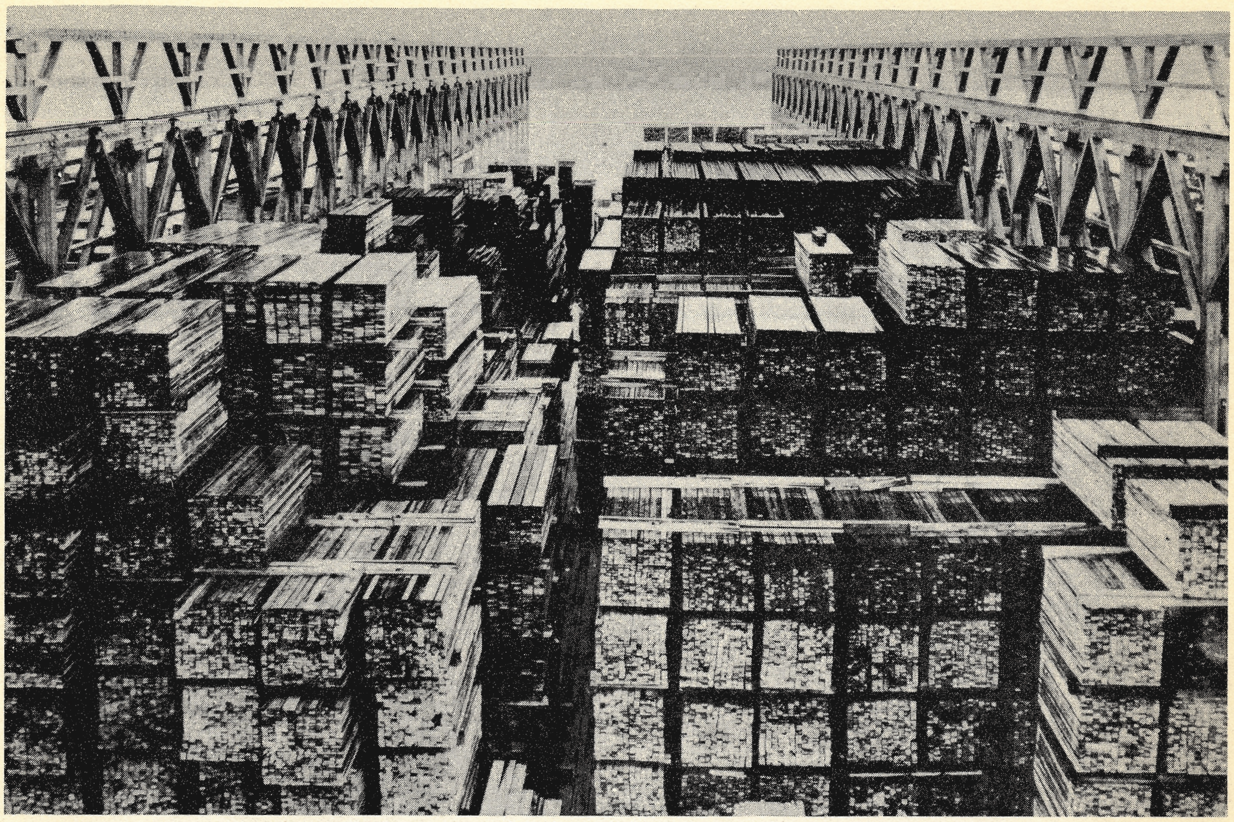


PLATE 2.—Douglas Fir and Western Red Cedar. Unit piling for loading by travelling crane.

DOUGLAS FIR

Pseudotsuga taxifolia (Poir.) Britton

Douglas fir is sometimes called British Columbia pine, Columbian pine, and, in some markets, Oregon pine, but these names are gradually being discontinued. It is found in British Columbia in all parts of the southern half of the province, except the west coastal district north of Vancouver Island, the mountain regions above its growth limit, and certain parts of the interior dry-belt district. It is also found in southern Alberta on the east slope of the Rocky Mountains. The best forests in British Columbia, however, are on Vancouver Island and the adjacent mainland.

Occasionally Douglas fir reaches a diameter of 12 feet and a height of over 300 feet. In a good forest it runs from 3 feet to 6 feet in diameter and from 150 feet to 200 feet in height. In such forests the trunk is clear of branches for about two-thirds or more of its height, and, therefore, produces a high percentage of clear lumber, and large structural timbers of high quality.

Douglas fir has a thin sapwood, generally less than 2 inches in depth, and quite light in colour; the heartwood ranges from a decided yellow tinge to a reddish brown; these variations give rise to the terms "yellow fir" and "red fir", the difference in colour of the wood being generally attributable to age, rate of growth, and other growth conditions. There is a pronounced difference in colour between spring-wood and summer-wood, which gives the wood a very distinctive figure when sawn flat-grain or when rotary-cut for veneer.

With the exception of western larch, Douglas fir is the heaviest Canadian commercial softwood, weighing about 34 pounds per cubic foot in the air-dry condition. It is also among the hardest of the softwoods and for that reason is used for purposes requiring hard and continuous wear. It is a very strong wood, especially in relation to its weight, and has become one of the best-known timbers in the world market, not only for heavy structural purposes but also for a wide variety of other uses.

PLATE 3.—Roof of Western Red Cedar, Knox Presbyterian Church, Ottawa.

The wood is of intermediate durability, and the heartwood is not subject to staining or moulding in seasoning. The tree is remarkably healthy, and little decay is found in green lumber. The wood, untreated, gives good service for railway ties, piling, bridge timbers, culverts, and other such uses, but for long service in conditions favouring decay it should be treated with a preservative, after incising to improve penetration. The sapwood may be treated quite readily; the heartwood is more refractory, but processes have been developed which give excellent results.

Douglas fir is an easy timber to season, either in the open air or in a dry-kiln, little trouble occurring through checking, twisting, or cupping.

Typical Uses

Heavy structural timbers	Railway cars
Piling	Shipbuilding
Windows and doors	Tanks and silos
Paving blocks	Masts and spars
Mine timbers	Telephone poles (treated)
Cross-arms	Veneers and plywood
Railway ties	Barges
Wood-stave pipe	Dock and harbour works

Flooring and flooring blocks
Slack and tight cooperage
Agricultural implements and truck bodies
Interior and exterior finish

THE TRUE FIRS

Abies

Four species of true fir are found in Canada. Three of these occur only in Western Canada; the fourth (balsam fir) is found in the Eastern Provinces, extending into a portion of Western Canada. These species are balsam fir, alpine fir, amabilis fir, and grand fir.

Balsam fir, *Abies balsamea* (L.) Hill, is also called fir, white fir, and balsam. It is widely distributed in Canada from the Atlantic seaboard through the Eastern Provinces and the northern part of the Prairie Provinces to Great Slave Lake and northward almost to Alaska. It is not a large tree, generally 1 foot to 2 feet in diameter and 50 to 60 feet in height, and occurs most frequently with white, red, and black spruce. It weighs about 24 lbs. per cubic foot when air-dry.

Alpine Fir, *Abies lasiocarpa* (Hook.) Nutt., is also known as mountain fir, western balsam fir, white fir, and Rocky Mountain fir. In Canada it is found in British Columbia, Alberta, and Yukon Territory, but is not found on Vancouver Island or the Queen Charlotte Islands, or in the southern coastal district of British Columbia. Generally, it is found growing between 2,000 to 7,000 feet. In the interior of British Columbia, where its chief commercial stands occur, it is associated with Engelmann spruce, Douglas fir, and lodgepole pine. It is not a large tree, generally running in diameter from 1 to 2 feet and in height from 60 to 70 feet.

Amabilis Fir, *Abies amabilis* (Dougl.) Forb., is also called silver fir, white fir, and (locally in British Columbia) larch. In Canada it is found from the Alaska boundary to the southern boundary of British Columbia, generally on the western slope of the Coast Range and on Vancouver Island. It occurs in stands of Douglas fir, western hemlock, western red cedar, and Sitka spruce. Amabilis fir attains a height of 150 to 175 feet and a diameter of 3 to 4 feet, but generally in a forest stand it is from 18 inches to 3 feet in diameter and 75 to 110 feet in height. It weighs about 26 pounds per cubic foot, air-dry.

Grand Fir, *Abies grandis* (Dougl.) Lindl., is also called lowland fir, white fir, western balsam, larch (locally in British Columbia), and giant fir. In British Columbia it is found only in the southern coastal district and in limited quantities in the Interior Wet Belt of the province and is generally associated with Douglas fir, western red cedar, and western hemlock. Grand fir grows to a diameter of 2 to 3 feet and a height of 100 to 125 feet.

The wood of all four true firs is very similar in appearance and texture. It is soft and light in colour, though amabilis fir is somewhat darker than the other three species. In properties, fir is closely similar to spruce, though inclined to be more open in texture and more brittle. When seasoned, the wood has practically no taste or odour. It takes a good finish and holds nails well. Where the firs occur with spruce, they are frequently graded with it for ordinary purposes. Amabilis fir and grand fir are associated with western hemlock, which in appearance they resemble to a considerable degree. For many of the purposes to which western hemlock is put, these firs are quite suitable, for example, boxes and pulp; for more exacting uses such as interior finish, structural purposes, and flooring, western hemlock is superior. All the true firs are used ex-

tensively for pulp and paper, though they are considered somewhat inferior to spruce for this purpose.

The firs are of low durability under conditions favouring decay.

Typical Uses

Pulp	Shiplap
Boxes and crates	Slack cooperage
Light and medium construction	

EASTERN HEMLOCK

Tsuga canadensis (L.) Carr.

This species is also known as hemlock, Canadian hemlock, and white hemlock. Eastern hemlock is usually from 1½ to 2 feet in diameter and from 50 to 70 feet in height, though occasionally larger trees are found. In forest stands the trunk is straight and fairly free of branches. It is found from Nova Scotia westerly to Lake Superior, south of the height of land between the Great Lakes and Hudson Bay drainages, generally mixed with pine or hardwoods.

The wood is light buff in colour with a reddish-brown tinge. The annual rings are quite distinct. It weighs about 29 pounds per cubic foot air-dry, is inclined to be somewhat splintery and cross-grained, and, though used to some extent in the dressed condition, is more often used for rough construction work. It is of moderate strength, though not so strong as western hemlock.

It is rather difficult to season on account of its tendency to twist. Its shrinkage in seasoning is moderate, corresponding closely to that of white spruce.

Typical Uses

Bridge planks	General construction
Railway ties (treated)	Boxes and crates
Pulp	Structural timbers

WESTERN HEMLOCK

Tsuga heterophylla (Raf.) Sarg.

Western hemlock is sometimes called British Columbia hemlock, and hemlock. It is one of the most important woods growing in British Columbia. It frequently attains a height of 150 to 200 feet and a diameter of 3 to 4 feet, though generally it is from 20 to 30 inches in diameter. In a forest stand the trunk is straight and clear of branches for about three-quarters of its length.

Western hemlock is found from Alaska southward along the whole British Columbia coast. It is also found in the interior of British Columbia in certain areas where there is abundant rainfall. On the coast it occurs with Douglas fir, Sitka spruce, and western red cedar, and in the interior of the province with cedar, Engelmann spruce, and the true firs.

As a rule western hemlock is fine-textured and uniform. The wood is generally fairly light in colour, though not as light as spruce. Sometimes it has a pinkish to reddish-brown tinge, with little difference in colour between the sapwood and heartwood. The wood is normally free of resin, a factor of importance for certain kinds of boxes. Western hemlock is among the heavier Canadian softwoods, its weight being about 30 pounds per cubic foot air-dry. The wood, although not so hard as Douglas fir, is considerably harder than spruce and makes a good flooring material. The grain, though not so pronounced as that of Douglas fir, is quite distinctive, and the wood is highly regarded for interior finish and decoration. It takes a good finish, holds nails and screws well, and is less inclined than is Douglas fir to split in nailing.

Although not so strong as Douglas fir, western hemlock ranks high in strength properties and can be used for many of the purposes for which Douglas fir is employed: it cannot be ranked among the more durable woods, especially in exposed situations favouring fungus attack. For ordinary purposes it is comparable with spruce in durability.

When green, it has a very high moisture content and does not season so rapidly or so easily as Douglas fir. With care, however, it can be seasoned very satisfactorily in the open air or in dry-kilns. It shrinks considerably in the process, but holds its shape quite well if properly cared for.

Typical Uses

General construction	Interior finish
Railway ties (treated)	Boxes and crates
Enamelled furniture	Kitchen cabinets
Broom handles	Flooring and ceiling
Pulp	
Poles and cross-arms (treated)	

MOUNTAIN HEMLOCK

Tsuga Mertensiana (Bong.) Carr.

The terms black hemlock, alpine spruce, and mountain hemlock-spruce are sometimes applied to this species, owing to the character of the foliage. The leaves are dark green to blue-green and spreading, but not two-ranked as in other hemlocks.

Mountain hemlock is an alpine or sub-alpine species occurring throughout the southern coastal region of British Columbia from about 2,500 to 6,000 feet elevation, descending almost to sea-level in more exposed or very wet areas in the north. It also occurs in higher mountain areas drained by the Columbia and Skeena Rivers. In favourable areas it may reach a height of 150 feet with diameters up to 4 feet, but in commercial stands at fairly high altitudes it is usually 80 to 90 feet tall with correspondingly smaller diameters, while near the limit of growth it is dwarfed and scrubby. In some areas it is found closely associated with western hemlock. Lower branches are persistent except in crowded stands, so that the percentage of clear lumber is small.

The wood is close-grained, pale reddish-brown in colour, hard, tough, and high in strength. It is very similar to western hemlock in its characteristics, but is somewhat more dense. In recent years, with the expansion of logging operations, more of this wood is coming into the market. It is usually marketed with western hemlock and is used for the same purposes.

WESTERN LARCH

Larix occidentalis Nutt.

Other names used for this species are larch, western tamarack, and tamarack. Western larch, in Canada, is confined to the southeastern part of British Columbia. It is seldom found in pure stands, but is usually mixed with Douglas fir, lodgepole pine, Engelmann spruce, alpine fir, and western hemlock. It is generally from 2 to 3 feet in diameter and 100 to 140 feet in height, but frequently attains a diameter of 4 feet and a height of 180 feet.

The wood is hard and strong, in these respects resembling Douglas fir more closely than any other Canadian softwood. The heartwood is a deep reddish-brown in colour; the sapwood is much lighter and of a yellowish-brown shade. There is considerable contrast in colour between the spring-wood and summer-wood, which gives it a pronounced figure when sawn flat-grain or when rotary-cut. It is somewhat difficult to work but takes a smooth, hard finish. It seasons fairly well, though some difficulty is encountered with warping and checking. The wood is of intermediate durability, approaching Douglas fir in this respect. On account of its durability, strength, and hardness, it is suitable for heavy structural purposes. It weighs about 38 pounds per cubic foot, air-dry.

Typical Uses

Railway ties	Car decking
Heavy construction	General construction
Flooring and ceiling	Piling
Tanks	Plywood
Interior and exterior finish	

TAMARACK

Larix laricina (Du Roi) K. Koch

Other common names for this species are eastern larch, hackmatack, black larch, and, in the Maritime Provinces, juniper. Tamarack is found from Labrador and the Maritime Provinces to the Rocky Mountains and north to the mouth of the Mackenzie River. In its southern range it is generally a swamp species, but farther north it grows on well-drained sites.

It is usually about 1 foot to 2 feet in diameter and 60 to 70 feet in height. The wood is fairly hard and is one of the strongest softwoods of Eastern Canada. It is of a dark reddish-brown colour and inclined to be somewhat coarse in texture. Tamarack is not a very important lumber species, but is quite valuable for a number of special purposes on account of its hardness, strength, and durability. It weighs about 35 pounds per cubic foot, air-dry.

Typical Uses

Railway ties	Boat-building
Piling	Planking
Water pipes	Tanks
Boxes and crates	Silos

JACK PINE

Pinus Banksiana Lamb.

Jack pine is also called princess pine, grey pine, and Banksian pine. In favourable sites it may attain a height of 90 feet and a diameter of 2 feet or more, but usually it is 10 to 20 inches in diameter and 60 to 70 feet in height. In open forests jack pine is very branchy, but in a pure or mixed dense forest it develops a straight, clear trunk. This tree is found in Canada from Nova Scotia to the Rocky Mountains and northern Alberta, where it meets lodgepole pine, which it closely resembles.

The wood is quite light in colour. It is of medium hardness, in this respect being considerably harder than white pine. Jack pine weighs about 31 pounds per cubic foot, air-dry. It works and finishes well. As the tree is small, it produces little clear lumber but a good grade of common lumber useful for a

variety of purposes. It holds nails well, and for this reason is a valuable box and crating material.

For exposed work it is moderately durable and has been used very extensively in Canada, untreated, for railway ties, but for long service it should be treated with a preservative. When treated, it is used extensively for telegraph and telephone poles.

Jack pine seasons without difficulty and has comparatively low shrinkage factors, approaching white pine in this respect. Its shrinkage in seasoning is also very uniform and therefore little difficulty is encountered through warping and twisting.

Typical Uses

General construction	Piles
Railway ties	Mine timbers
Silos	Boxes and crates
Pulp (chemical)	Telephone poles (treated)

LODGEPOLE PINE

Pinus contorta Dougl. var. *latifolia* Engelm.

This species is also known as black pine and western jack pine. Lodgepole pine extends over nearly all of British Columbia and into the Yukon Territory. It is also found in Alberta on the eastern slope of the Rocky Mountains, in the Cypress Hills, and over the northern portion of Alberta west of Lesser Slave Lake.

The tree varies considerably in size in different districts. On the coast it is quite a small scrubby tree from 6 to 20 inches in diameter and 20 to 40 feet in height. On the more favourable sites, it is 12 to 24 inches in diameter and 50 to 100 feet in height.

The wood is light in colour, the sapwood sometimes being almost white. It is soft, straight-grained, and of fine, uniform texture. It takes a good finish, and though, on account of its size, it does not produce much high-grade lumber, it yields a good grade of small, tight-knotted stock, in quality not dissimilar to that of Engelmann spruce or jack pine.

Lodgepole pine seasons easily and uniformly. It is of moderate durability. It takes paints and varnishes satisfactorily. It has good nailing properties and is suitable for boxes. It weighs about 29 pounds per cubic foot, air-dry.

Typical Uses

Shiplap	Pulp (sulphate)	Boxes and crates
Piling	Grain doors	Mining timbers

Light and medium construction
Telephone and telegraph poles (treated)
Railway ties (especially if treated)

PONDEROSA PINE

Pinus ponderosa Laws.

Other common names for this species are western yellow pine, bull pine, yellow pine, and British Columbia soft pine. In Canada, ponderosa pine is confined to the drier portions of the southern interior of British Columbia and to the lower altitudes in this district, generally between 1,500 and 2,500 feet above sea-level. It is usually found in fairly pure stands, but in some situations occurs mixed with Douglas fir and, at the higher altitudes, with lodgepole pine. Ponderosa pine is ordinarily from 2 to 2½ feet in diameter and 75 to 100 feet in height, but occasionally reaches a diameter of 5 or 6 feet and a height of 160 to 170 feet.

The wood varies in colour. Mature trees have a very thick sapwood, which is pale yellow. The heartwood is much darker, ranging from a deep yellow to a reddish brown. The summer-wood ring in the heartwood is quite sharply defined, giving wood cut from this portion considerable figure. The sapwood yields a very fine quality of lumber, light in weight, fairly soft and uniform in texture, suitable for pattern stock, fine woodwork, and other exacting uses. In large old trees the heartwood is considerably heavier than the sapwood. The wood is fairly strong, and works easily and smoothly without splitting or splintering. It takes paints, stains, and varnishes well, and seasons readily, though care must be exercised on account of the susceptibility of the sapwood to blue-staining if not properly piled on a suitable site. It has good nail-holding properties and is used extensively for containers. It weighs about 32 pounds per cubic foot, air-dry.

The sapwood is not very durable, but the heartwood is moderately durable. It is the most resinous of the Canadian commercial pines.

Typical Uses

Sash and doors	Patterns
Boxes and crates	General construction
Car lining	Cabinet-work
Agricultural implements	Turnery
Kitchen furniture	

Interior and exterior finish

RED PINE

Pinus resinosa Ait.

This species is frequently called Norway pine and Canadian red pine. The name "red pine" is very

significant and appropriate on account of the distinctive reddish-brown colour of the bark. Red pine is ordinarily from 75 to 125 feet in height, and attains a diameter of from 20 to 30 inches. The trunk is very erect, with little taper, and in forest stands is usually clear of branches for about three-quarters of its length. Red pine is found from the Atlantic Ocean to Lake Winnipeg in Manitoba, but, like white pine, it is not found in large quantities north of the St. Lawrence River drainage.

It has a thick sapwood which is of a pale yellow colour; the heartwood is darker and of a pale brown to reddish tinge. There is a good deal of contrast in colour between the spring-wood and summer-wood, especially in the heartwood, which gives the wood considerable figure when cut flat-grained. Although a comparatively light wood, it is heavier and harder than white pine, is easy to work, takes a good finish, and holds nails and screws well. It weighs about 28 pounds per cubic foot, air-dry. It is fairly strong, excelling white pine in this respect, and is used extensively as a structural timber.

For ordinary purposes, it is moderately durable. The wood can be quite readily treated with preservatives, especially the sapwood, and is then valuable for poles and piles.

It seasons easily and uniformly, with little checking, twisting, or cupping; it is readily kiln-dried, and its finishing qualities are improved in the process, through the setting of the resin. It shrinks in seasoning more than white pine, but may be classed among the woods having medium shrinkage.

Typical Uses

Structural timbers	Windows and doors
Railway cars	Agricultural implements
Tanks and silos	Boxes and crates
Cabinet-work	Piling (treated)

Telephone poles (treated)
Flour- and grain-milling equipment
Interior and exterior finish

WHITE PINE

Pinus Strobus L.

White pine is sometimes called eastern white pine, pattern pine, Quebec yellow pine, Ottawa pine, and Weymouth pine. Under favourable conditions it reaches a height of 175 to 200 feet, and a diameter of 5 feet, but in the average forest stand it is generally from 90 to 125 feet in height and from 20 to 30 inches in diameter. It is found in Eastern Canada from the Maritime Provinces to eastern Manitoba, the most important stands being in the St. Lawrence River drainage area, principally in the Ottawa Valley in Ontario and Quebec and in the Great Lakes region of Ontario.

White pine was for many years the most important sawn lumber species of Canada, and, though its production is now exceeded by that of Douglas fir, spruce, and hemlock, it is still Canada's fourth most important timber from a production standpoint. The timber is very highly regarded for a wide variety of uses and in particular for many special uses of an exacting nature. Its sapwood is almost white and the heartwood of a creamy white to a light straw-brown shade.

It is the softest of the Canadian pines and works exceptionally well under tools, taking a smooth, satin-like finish. It is quite a light wood, in the air-dry condition weighing about 24 pounds per cubic foot. It is not as strong as most of the hard pines, and therefore is not used for heavy structural work, but for ordinary construction, where long life is of greater importance than strength, it is very serviceable.

A most important characteristic of white pine is its low shrinkage. In this respect it is superior to all other Canadian species except the cedars. It seasons easily and uniformly, though care has to be exercised to prevent staining, especially of the sapwood. On account of its low shrinkage and uniform texture it is used extensively for patterns, window sash and frames, and other uses where stability of size is important. The wood takes stains, paints, and varnishes exceptionally well. It has good nail-holding properties and does not tend to split or splinter. White pine makes excellent wood flour.

Typical Uses

Windows and doors	Woodenware
Match splints	Wood flour
Ship- and boat-building	Cabinet-work
Shelving	Musical instruments

Engineering works
Interior and exterior finish
Patterns, drawing boards, and artists' supplies
Light and medium construction

WESTERN WHITE PINE

Pinus monticola Dougl.

Western white pine is also called silver pine and white pine. It is a tall tree with a clear bole tapering very little. Occasionally it attains a diameter of 4 feet and a height of 175 feet, but in an average forest it is about 75 to 125 feet in height and 2 to 3 feet in diameter. In Canada it is found only in southern British Columbia, generally mixed with western hemlock, Douglas fir, and the true firs. It is found in some of the valleys of the interior of British Columbia where there is good rainfall, and on Vancouver Island and the adjacent mainland.

The wood of western white pine is very similar to that of eastern white pine. It is very light in colour, straight-grained and uniform in texture, slightly harder than eastern white pine, and works well under tools. It takes an excellent finish, is very suitable for painting or enamelling, holds nails well, and is a most useful wood for a wide variety of purposes.

Its strength is closely similar to that of the eastern white pine. It is fairly durable, though generally not rated so highly in this respect as the eastern white pine. Air-dry, it weighs about 26 pounds per cubic foot. In the open it seasons with little checking or warping and can be kiln-dried satisfactorily. In drying, it shrinks slightly more than the eastern white pine, but less than spruce.

Typical Uses

As given for eastern white pine.

SPRUCE

Picea

Five species of spruce are found in Canada, namely, white, red, black, Engelmann, and Sitka. The wood of all the spruces is very similar in appearance, and in the uses to which it is put; excepting in so far as the size of the trees (which differs greatly with the

PLATE 4.—Modern House of White Pine.

PLATE 5.—Eastern Spruce Pulpwood, Corner Brook, Newfoundland.

species), may determine certain of the uses. Two of the species, Engelmann and Sitka spruce, are found only in Western Canada; red spruce is found only in a portion of Eastern Canada, and white spruce and black spruce are found over a very wide range, extending from Newfoundland westward and northward to the Yukon and the mouth of the Mackenzie River.

As sawn lumber in Canada, spruce, in volume of output, is first. When its use for pulp and paper is also taken into account, it is Canada's most important wood.

White Spruce, *Picea glauca* (Moench) Voss—This species is also called northern spruce, Canadian spruce, and cat spruce (Nova Scotia). Generally it is about 50 feet in height and 1½ to 2 feet in diameter, but occasionally reaches a diameter of 4 feet and a height of 100 feet. It is one of the most widely-distributed trees in Canada, extending from Labrador to northern British Columbia and the Yukon Territory, and in a northerly direction practically to the limit of tree growth. It sometimes occurs in pure stands, but is often found with red spruce in the eastern part of its range, with black spruce practically throughout its range, and with tamarack, birch, and poplar. In the foot-hills of Alberta and in central British Columbia it occurs with Engelmann spruce. Western white spruce is recognized as a variety.

The wood varies from almost white to a pale yellow colour, generally with little contrast between the sapwood and heartwood. It is light in weight, and soft, is very easily worked to a smooth silky finish, and takes paint well. It is almost tasteless and odourless when seasoned, and hence is very valuable for food containers. It has good nail-holding properties and does not tend to split in nailing. It seasons fairly easily. White spruce is of medium strength and among the softwoods is noted for its resilience, which makes it a favoured wood for scaffolding planks and similar uses. It is not considered very durable in situations favourable to decay, but for

ordinary construction gives good service. It has good resonance properties, a feature of value for sounding-boards in musical instruments. White spruce has a long, slender, colourless fibre which renders it of particular value in the pulp and paper industry. It weighs about 26 pounds per cubic foot, air-dry.

Typical Uses

Pulp	Piano sounding-boards
Shop fittings	Paddles and oars
Agricultural implements	Cooperage
Ladder stock	Organ pipes
Kitchen cabinets	Shelving

Light and medium construction
Food containers, boxes, etc.

Black Spruce, *Picea mariana* (Mill.) B.S.P.—Black spruce is also called swamp spruce and water spruce. It is a comparatively small tree, generally 35 to 40 feet in height and 6 to 10 inches in diameter, though on favourable sites it may be larger. It is found from Newfoundland right across Canada to the Yukon Territory and north to the mouth of the Mackenzie River. Its wood is very similar to that of white spruce, but it is somewhat heavier, stronger, harder, and more durable. On account of its size it is not so important a lumber species as white spruce, but is a very valuable pulpwood and is also used for mine timbers and other similar purposes. It weighs about 30 pounds per cubic foot, air-dry.

Red Spruce, *Picea rubens* Sarg.—Red spruce is sometimes called yellow spruce. It is ordinarily from 50 to 75 feet in height and 1 foot to 2 feet in diameter. In Canada it is found only in Nova Scotia, New Brunswick, Prince Edward Island, and to a limited extent in southern Quebec and eastern Ontario. The wood of red spruce is very similar to that of white spruce; but the annual growth-ring is inclined to be more pronounced than in white spruce, giving it a more clearly defined figure when sawn. It is slightly harder, heavier, and stronger than white spruce, but the difference is so small that no attempt is made to separate them in marketing. It is also a valuable pulpwood. Its uses are similar to those of white spruce. It weighs about 28 pounds per cubic foot, air-dry.

Sitka Spruce, *Picea sitchensis* (Bong.) Carr.—Sitka spruce is sometimes known as silver spruce, Menzies spruce, and coast spruce. It occasionally attains a diameter of over 10 feet and a height of 250 feet, though ordinarily it runs from 3 to 6 feet in diameter and 150 to 200 feet in height. It occurs throughout the coastal belt of British Columbia, but attains its best growth on the Queen Charlotte Islands.

Sitka spruce timber weighs about 27 pounds per cubic foot, air-dry. It is not as light in colour as some of the Canadian spruces, usually ranging from creamy white to a light pinkish tinge. There is very little difference in colour between the heartwood and sapwood, though generally the latter has not the pinkish tinge. While there is considerable difference in colour between spring-wood and summer-wood, the contrast is not so striking as in Douglas fir.

The wood is usually very straight-grained. It is easily worked and takes a smooth silvery finish. It takes nails without splitting and holds them well, takes paints and enamels well, and is practically tasteless and odourless. On account of the great size of the tree and its clear trunk, it produces a large

PLATE 6.—Sitka Spruce.

proportion of clear timber suitable for the manufacture of aeroplane wing-beams, struts, posts, and other parts. It does not splinter or shatter easily on impact. Like all the spruces, it is only moderately durable. The difficulty encountered through stain and mould in shipping green spruce by water through hot, humid zones may be overcome by air-seasoning for from 30 to 60 days before shipment. Sitka spruce is not difficult to season, especially in boards or small timbers, but care must be exercised in seasoning valuable, high-quality stock in large sizes. Sitka spruce can be kiln-dried without undue difficulty. Its shrinkage in drying is medium and similar to that of other spruces.

Typical Uses

Masts and spars	Organ pipes
Aeroplane construction	Kitchen furnishings
Woodenware	Oars and paddles
Pulp	General construction
Agricultural implements	Ladders
Shelving	Scaffolding

Food containers, boxes, etc.
Sounding-boards for musical instruments

Engelmann Spruce, *Picea Engelmanni* Parry—Other names for this species are mountain spruce, Rocky Mountain spruce, and western white spruce. It occurs throughout the interior mountain region of British Columbia and on the eastern slope of the Rocky Mountains. It is not found west of the summit of the Coast Range. In the southern part of the province it is found at altitudes of 3,000 to 5,000 feet, but in its more northerly range it is found in the valleys and on the mountain slopes at altitudes of 1,000 to 4,000 feet. It is usually from 1½ to 3 feet in diameter and 80 to 120 feet in height, but may attain a diameter of 6 feet and a height of 180 feet on favourable sites.

The wood is quite light in colour, straight-grained, and works well under tools, taking an excellent finish. It is very similar in properties to the white spruce of Eastern Canada. The tree is usually larger than white spruce and therefore produces a higher percentage of lumber clear of defects, suitable for special uses such as oars, paddles, and piano sounding-boards. It weighs about 27 pounds per cubic foot, air-dry.

Typical Uses

Engelmann spruce is used for the same purposes as white, black, and red spruce.

HARDWOODS (Broad-leaved trees)

RED ALDER

Alnus rubra Bong.

Red alder is also known as western alder and Oregon alder. It is confined to the Pacific Coast, and in Canada is found in the coastal district of British Columbia and on the adjacent islands. It is the only species of alder in Canada of significance commercially. The tree is about 8 to 20 inches in diameter and 30 to 60 feet high, though larger trees, 50 to 100 feet high, are occasionally found.

The wood is of a pale yellow to reddish-brown colour. Among the hardwoods it is of medium hardness and weight. It is uniform in texture and works well with tools, taking a smooth finish. It has a pleasing, subdued figure and when properly stained makes quite attractive furniture. It has good nail-holding properties and takes stain, enamel, and paint in a very satisfactory manner. It is not durable in exposed situations. It weighs about 28 pounds per cubic foot, air-dry.

Typical Uses

Furniture	Woodenware
Turnery	Novelties
Core-stock	Plywood
Cabinet-work	Charcoal

ASH

Fraxinus

Four species of ash are found in Canada, namely, white ash, blue ash, black ash, and red ash. Another, called green ash, which is considered a variety of red ash, is found in limited quantity. Of the five ashes, white ash is the most valuable.

White Ash, *Fraxinus americana* L., which is sometimes called Canadian white ash and American white ash, occurs in Canada from Nova Scotia to south-western Ontario. It is commonly 50 to 60 feet in height and 2 to 3 feet in diameter, but occasionally attains a height of 100 feet. The sapwood is nearly white; the heartwood varies from light brown to a reddish-brown shade. It has a pronounced figure which is, however, not so attractive as that of oak, and is therefore not so highly valued as oak for furniture, and interior finish. The wood is fairly hard and heavy (about 44 pounds per cubic foot, air-dry) but is particularly noted for its toughness. It works quite well with tools, has comparatively low shrinkage, and

seasons uniformly without distortion. It is of intermediate durability.

Typical Uses

Aeroplanes	Trunks
Bentwood	Refrigerators
Vehicles	Car and boat frames
Handles	Interior finish
Shop fixtures	Agricultural implements
Furniture	Church pews

Sporting goods (especially skis, baseball bats, and hockey sticks)

Blue Ash, *Fraxinus quadrangulata* Michx., is found only in a limited area in southwestern Ontario, bordering on Lakes Erie and St. Clair. It occasionally reaches a height of 60 to 70 feet, but is generally much smaller and, on account of its limited supply, is of little commercial importance.

Black Ash, *Fraxinus nigra* Marsh., is usually found growing in swamps and river-bottoms from the Gulf of St. Lawrence to Manitoba. It attains a height of 60 to 70 feet, but is very slender. It is not nearly so hard or strong as white ash, but a certain amount of it is used for interior finish, cabinet-work, and fixtures. It has quite a pleasing grain and takes a good finish. It weighs about 35 pounds per cubic foot, air-dry.

Red Ash, *Fraxinus pennsylvanica* Marsh., is found in limited quantities in southeastern Quebec and throughout southern Ontario. It occurs also near Lakes Winnipeg and Winnipegosis in Manitoba and in some of the river-bottoms of eastern Saskatchewan. It is a small tree, rarely over 40 feet in height, and resembles white ash, but is not so strong and tough, nor as durable.

Green Ash, *Fraxinus pennsylvanica* Marsh. var. *lanceolata* (Borkh.) Sarg., is found from southwestern Quebec to Georgian Bay and also from the west end of Lake Superior throughout the southern portion of the Prairie Provinces. It is a small tree, rarely exceeding 50 feet in height. The wood resembles to some extent that of white ash, but is much inferior in hardness, strength, and toughness. It weighs about 35 pounds per cubic foot, air-dry.

BASSWOOD

Tilia americana L.

Basswood is sometimes called whitewood. It is found in Canada from the Atlantic Coast westward to southern Manitoba. Ordinarily it is about 60 to 70 feet in height and from 20 to 30 inches in diameter, but sometimes it reaches a height of over 100 feet and a diameter of 4 feet.

The wood is light in colour, shading from a creamy white to a light brown. It is one of the softest and lightest in weight of the Canadian hardwoods, in these respects resembling white pine more than it does the hardwoods. It weighs about 29 pounds per cubic foot, in the air-dry condition.

Basswood works exceptionally well and is valued for hand-carving and modelling. It takes a smooth finish, takes and holds paints and lacquers in an excellent manner, and has good gluing and nail-holding properties. It has practically no taste or odour and is, therefore, valuable for containers for foodstuffs.

Basswood is not a strong wood in comparison with the heavier hardwoods such as birch or maple, but is more nearly similar to the lighter pines in strength. It is not a durable wood when exposed to conditions favouring decay. It seasons without undue difficulty with respect to checking and twisting; it has high shrinkage factors for its weight, but after proper seasoning does not change dimension unduly. It is one of the most widely useful woods among the softer hardwoods.

Typical Uses

Piano keys	Drawing-boards
Turnery	Blinds
Baskets	Patterns and models
Woodenware	Excelsior
Wood specialties	Picture frames
Boxes and crates	Musical instruments
Barrel headings	Handicraft work
Canoes	

BEECH

Fagus grandifolia Ehrh.

This species is also called American beech and red beech. In Canada, it is found from Nova Scotia to the north shore of Georgian Bay. It occasionally occurs in pure stands, but is generally associated with maple, birch, and other native hardwoods. In a forest stand it may attain a diameter of 4 feet and a height of 80 feet, but generally it is 1½ to 2 feet in diameter and 40 to 50 feet in height.

The wood is hard, heavy, (about 46 pounds per cubic foot, air-dry) and strong, closely resembling yellow birch and maple in these respects, though for

most purposes it is considered inferior in quality to these species. The sapwood is very light in colour; the heartwood varies from a pale brown to a reddish-brown shade. It is rather difficult to season, but finishes with a smooth hard surface. It is quite a good wood for turnery and holds glue well. It has high shrinkage, and is not very resistant to decay.

Typical Uses

Flooring	Handles and turnery
Furniture frames	Wood distillation
Railway ties (treated)	Woodenware
Cooperage	Laundry appliances

BIRCH

Betula

Nine species of birch are found in Canada, but only two, namely, yellow birch and white birch, are of much commercial importance. Another species, western white birch, found in British Columbia, grows to quite a large size, but occurs in such small quantities as to be of limited commercial significance. The remaining birches are, generally, so small that they are of little value except for fuelwood or minor purposes.

Yellow Birch, *Betula lutea* Michx. f.—This species is sometimes called curly birch, black birch, red birch, and hard birch. It is found from Newfoundland westward to the east side of Lake Superior, also from the west end of this lake to the Lake of the Woods along the boundary between Canada and the United States. It is the most important commercial hardwood in Canada from the standpoint of its fine

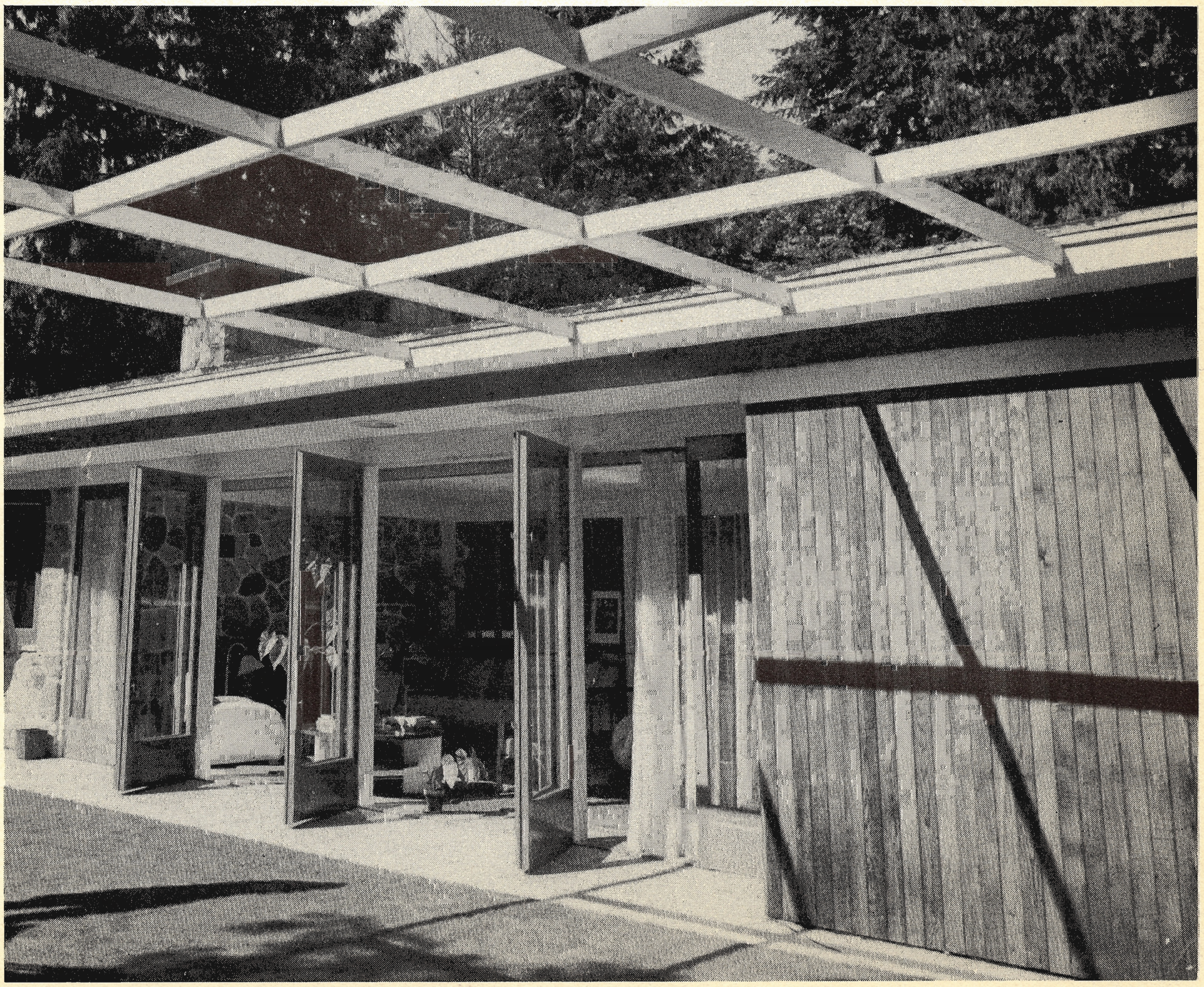


PLATE 7.—A Modern Home, Vancouver, B.C.

qualities and its abundance. It is the largest of the birches native to Canada, sometimes reaching 100 feet in height and 3 feet in diameter. In the forest it is usually from 20 to 30 inches in diameter and from 60 to 80 feet in height.

The sapwood is light yellow in colour and the heartwood a distinctive reddish brown. The wood is of uniform texture and, although the grain is not very pronounced, yellow birch produces lumber with a pleasing subdued figure. The wood may be ranked among the heavy hardwoods. It is similar to white oak in hardness but is not so hard as maple. It is a little lighter in weight than oak and maple and is a hard-wearing wood of wide utility. It weighs about 44 pounds per cubic foot, air-dry.

Yellow birch takes a smooth finish and is easily worked under tools. It is used extensively as a furniture wood, and for high-class interior finish and decoration. Some logs produce curly-grained birch, which is much prized for furniture and for veneers. Yellow birch has high mechanical properties, very similar to those of white oak, though lower in toughness.

The wood is not very durable and should not be used, without preservative treatment, in conditions favourable to decay. It can, however, be treated without great difficulty and when treated is used extensively in Canada for railway ties.

The heavy hardwoods are generally considered difficult to season, but yellow birch may be seasoned with little de-grade either in the open air or in dry-kilns. In general, where kiln-dried material is required, the stock is first air-seasoned. The shrinkage in seasoning is high, but there is little difference between the radial and the tangential shrinkage, and consequently not much trouble through distorted stock.

Typical Uses

Flooring	Rifle furnishings
Furniture	Railway ties
Doors	Railway coach work
Interior finish	Turnery
Cabinet-work	Tin-plate boxes
Vehicles	Shuttles, spools, bobbins
Boxes and crates	Parquetry
Veneers and plywood	Cooperage
Agricultural implements	

White Birch, *Betula papyrifera* Marsh.—This species is also known as paper birch, canoe birch, and silver birch. It has a very wide range in Canada, being found from Newfoundland westward to the Yukon Territory and northward nearly to the mouth of the Mackenzie River. The tree rarely exceeds 70 feet in height and 18 inches in diameter. Generally it is from 50 to 60 feet in height and 10 to 14 inches in diameter, and is comparatively free of branches.

The wood is creamy white in colour. Among the hardwoods it may be classed as of medium hardness and weight, in these two respects being inferior to yellow birch, maple, oak, beech, and the other heavy hardwoods, but superior to poplar, basswood, chestnut, and other light hardwoods. It weighs about 40 pounds per cubic foot, air-dry.

The wood can be worked easily and, although not as strong as yellow birch, is quite strong, tough, and serviceable. It is not durable in exposed positions. With care it seasons quite satisfactorily, its shrinkage being somewhat less than that of the heavier hardwoods such as yellow birch, hard maple, and white oak.

Typical Uses

Spools	Brushes
Bobbins	Hoops
Dowels	Novelties
Clothes-pins	Wash-boards
Shoe-pegs	Crates
Woodenware	Toys
Buckets	Crutches
Veneers and plywood	

Western White Birch and Alaska White Birch—Several types of birch occur in British Columbia, the Yukon Territory, and Alaska, and may be included under the general designation of western birch. They are considered as varieties of the white or canoe birch, *Betula papyrifera* Marsh.; there is generally a broad overlapping in their ranges, and the characteristics of each may vary considerably.

Commercially, the western white birch, *B. papyrifera* Marsh. var. *commutata* (Regel) Fern., is the most important, with its principal distribution in the Fraser River Valley and in the valleys of the southern interior of British Columbia where rainfall is abundant. The Alaska white birch, *B. papyrifera* Marsh. var. *humilis* (Regel) Fern. & Raup, has a more northern range, and extends from Saskatchewan to Alaska. The Kenai birch, *B. pap.* Kenaica, has a limited distribution, largely confined to the Alaskan coast.

A fourth variety, the northwestern white birch, *B. papyrifera* Marsh. var. *subcordata* (Rydb.) Sarg., is a small tree with a local range along the southern boundary of British Columbia and part of Alberta.

In the southern portion of its range, western birch (all varieties) averages 60 to 70 feet high and 12 to 16 inches in diameter, with a rate of growth of 6 to 10 rings per inch. Occasionally, trees from 100 to 120 feet high, and up to 3 feet in diameter are found. In the north, the average height is 40 to 60 feet, with a diameter of 10 to 14 inches, the largest trees seldom exceeding 80 feet high or 2 feet in diameter.

The wood is creamy white to a light tan in colour, with occasional darker streaks. It is very uniform in texture and does not show much figure, but it takes a beautiful finish that gives it a distinctive appearance. It is tough and strong, being very similar to eastern white birch in weight, hardness, and strength. It seasons readily and shows less tendency to shrink or warp than the heavier hardwoods. It is not durable in exposed locations.

The wood works easily and the uniformity of grain is a distinct advantage in the manufacture of veneers and plywoods for use in aircraft and other industries.

Typical Uses

Veneers and plywood	Flooring
Furniture	Desks and cabinets
Propeller stock	Interior finish

Spools, bobbins, and shuttles
Turnings, carvings, and novelties

WALNUT

Juglans

Only two species of walnut occur in Canada, namely, black walnut and butternut.

Black Walnut, *Juglans nigra* L.—This species occurs naturally in Canada in very limited amounts and only in southern Ontario bordering Lakes Ontario, Erie, and St. Clair, though in sheltered positions it has been grown farther north.

It is a large tree, from 50 to 90 feet in height and sometimes from 2 to 5 feet in diameter. The heartwood is dark in colour, varying from light brown to a dark brown, sometimes almost chocolate in shade; the sapwood is quite light. The wood is hard and strong, being closely similar to white oak in these properties. It is, however, not so heavy as white oak, weighing about 41 pounds per cubic foot in the air-dry condition.

It is easily worked and takes a particularly fine finish. For these reasons, as well as for its beautiful colour, it is highly regarded for furniture.

Typical Uses

Furniture	Caskets
Pianos	Interior finish
Aeroplane propellers	Rifle furnishings
Boats	Scientific instruments

Woodenware and novelties
Picture frames and mouldings

Butternut, *Juglans cinerea* L.—This species is sometimes called white walnut. It is found in New Brunswick, in the valley of the St. Lawrence, and throughout the hardwood region of Ontario east and south of Georgian Bay.

The tree is about 40 to 50 feet in height and 1 foot to 3 feet in diameter. The sapwood is light in colour, ranging from almost white to light brown; the heartwood is darker, but not so dark as that of black walnut, which it resembles somewhat in general appearance and texture.

The wood is light in weight (about 27 pounds per cubic foot, air-dry), soft and weak, ranking in these particulars among the soft hardwoods such as basswood: it is inclined to be somewhat coarse-grained, but works well and does not impart odour or taste. It takes stains well and can be finished to resemble black walnut. For a hardwood, it has low shrinkage factors and is used to some extent for patterns.

Typical Uses

Interior finish	Church pews
Furniture	Patterns
Cabinets	Store fixtures
Boat finishing	

CHESTNUT

Castanea dentata (Marsh.) Borkh.

This species is sometimes called sweet chestnut. In Canada it is found growing naturally only in that small part of southern Ontario lying between the Niagara River and Lake Ontario on the east and the Detroit River and Lake St. Clair on the west. It is from 70 to 80 feet in height and 2 to 3 feet in diameter, occasionally reaching a height of 100 feet. The quantity available in Canada is very limited.

The wood is pale brown in colour and is usually characterized by wide growth-rings which give the wood a pronounced figure; it works easily, seasons

well, and takes a good finish. Among the Canadian hardwoods it is of moderate strength and weight (about 31 pounds per cubic foot, air-dry), in these respects ranking considerably lower than birch, maple, and oak, but higher than basswood, poplar, and some of the softwoods. The heartwood is very durable, and for this reason chestnut has in the past been used to some extent for telephone poles, posts, and railway ties. It is rich in tannin.

Typical Uses

Interior finish	Office fixtures
Poles	Musical instruments
Railway ties	Tanks
Posts	Core-stock
Furniture	Tannin extraction

BLACK CHERRY

Prunus serotina Ehrh.

Black cherry is the only species of cherry in Canada which attains sawlog size. It is found from Nova Scotia to Lake Superior, reaching a height of 60 to 70 feet and a diameter of 1½ to 2 feet, usually as scattered trees growing with other hardwoods; it is nowhere plentiful. The wood is highly regarded for certain special uses; it has a rich reddish-brown colour and fine, even texture, and a pleasing figure, though not so pronounced as that of some of the other hardwoods. It takes a very fine polish and is valued for the better grades of furniture and cabinet-work. The wood seasons easily, and has comparatively low shrinkage and excellent gluing properties. It ranks high in strength and hardness, in these properties resembling yellow birch. It weighs about 37 pounds per cubic foot, air-dry.

Typical Uses

Furniture	Caskets
Cabinet-work	Patterns
Boats (interiors)	Railway cars (interiors)
Musical instruments	Printing blocks

ELM

Ulmus

Only three species of elm are native to Canada, namely, white elm, rock elm, and slippery elm, but several exotic species have been introduced for ornamental planting.

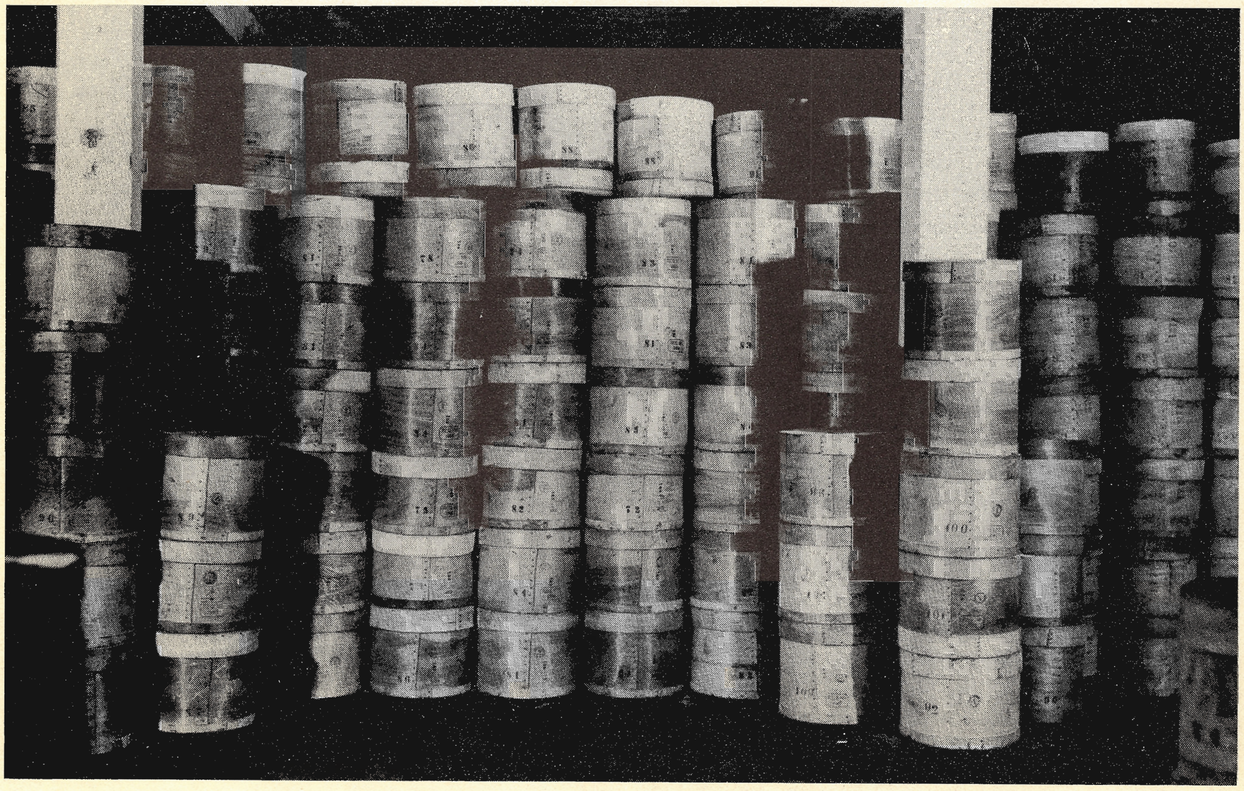


PLATE 8.—Cheese Boxes made of Elm Veneer.

White Elm, *Ulmus americana* L.—White elm is also called American elm, water elm, and swamp elm. It is one of the largest hardwood trees found in Canada, occasionally attaining a diameter of over 7 feet and a height of 125 feet. In the forest it is usually 2 to 3 feet in diameter and 50 to 90 feet in height, with a long clear trunk. It is found in all provinces of Eastern Canada and as far west as Saskatchewan, but not north of the height of land between the Hudson Bay and Great Lakes drainage areas.

The sapwood is light in colour, the heartwood pale reddish-brown. It is considerably lighter in weight and softer than yellow birch, white oak, and sugar maple, but in these respects is much superior to the softer hardwoods such as basswood and poplar. It weighs about 42 pounds per cubic foot, air-dry, works well under tools, and takes a good finish.

While not as stiff as the heavy hardwoods, it is a very strong wood and is especially valued for its toughness and good bending properties. It is therefore used for hoops, baskets, barrel staves, etc., which have to be bent to shape. It is moderately durable, seasons quite readily, and has medium shrinkage in seasoning.

Typical Uses

Machinery parts	Crating and boxes
Cheese boxes	Pails
Hockey sticks	Baskets
Caskets	Handles
Church pews	Ladders
Furniture	Boat-building

Slack cooperage (staves, hoops, etc.)

Rock Elm, *Ulmus Thomasi* Sarg.—Rock elm is sometimes called cork elm, hickory elm, and white elm. It grows to about 2 feet in diameter and 50 to 60 feet in height. In Canada it is confined to the southern parts of the Provinces of Quebec and Ontario. The wood is similar in colour to white elm, but the contrast between heartwood and sapwood is not so pronounced. It is a hard, heavy wood, exceeding considerably other Canadian elms and white oak in this respect. Its weight is about 49 pounds per cubic foot, air-dry.

Rock elm is a rather difficult wood to work, but finishes to a smooth surface. It holds nails exceptionally well, takes a good polish, and retains stains and paint satisfactorily. It is very strong, tough, capable of withstanding hard wear, and quite durable. Care has to be exercised in seasoning, as it is inclined to check and twist. It has high shrinkage in drying.

Typical Uses

Agricultural implements	Sleigh runners
Rockers (chair)	Bentwork
Gymnasium equipment	Ship's belting
Vehicles	Wharf and dock fenders
Tool handles	Ladder rungs

Doubletrees and whippletrees

Slippery Elm, *Ulmus rubra* Muhl.—This species is frequently referred to as red elm, slippery-barked elm, and soft elm. It occurs in Canada only in southern Ontario and southern Quebec, from the lower St. Lawrence River Valley to Lake Superior. It does not grow to as great a size as white elm, being generally about 50 to 60 feet in height and 1 to 2 feet in diameter. The wood is very similar to white elm in appearance, properties, and uses, and in the timber trade it is not differentiated from white elm.

HICKORY

Carya

Six species of hickory occur in Canada, the more important of which are bitternut, shagbark, mockernut, and pignut.

Bitternut Hickory, *Carya cordiformis* (Wangh.) K. Koch, is found in southern Ontario and southwestern Quebec. It is from 50 to 60 feet in height and 1 foot to 1½ feet in diameter. It weighs about 49 pounds per cubic foot, air-dry.

Shagbark Hickory, *Carya ovata*, (Mill.) K. Koch, sometimes called shellbark hickory, is found in Canada only in southern Ontario and southwestern Quebec. It is larger than bitternut, sometimes attaining a diameter of 2 feet or over and a height of 80 feet. It weighs about 50 pounds per cubic foot, air-dry.

Mockernut Hickory, *Carya tomentosa* Nutt., sometimes called whiteheart hickory, is found in Canada only in those counties of Ontario bordering Lakes Ontario, Erie, and St. Clair. It is the tallest of the hickories, occasionally attaining a height of 90 feet.

Pignut Hickory, *Carya glabra* (Mill.) Sweet, sometimes called brown hickory and black hickory, is found in Canada only in the Niagara peninsula and the counties bordering Lake Erie. It is from 40 to 60 feet in height and 2 to 3 feet in diameter.

While there are slight differences in the weight and strength of the different species of hickory, these

are not great, and all species are characterized by their great strength, hardness, and toughness. They exceed in importance all other Canadian woods where a combination of such qualities is required, and since they are procurable in Canada only in limited quantities, are looked on, to some extent, as specialty woods.

The sapwood is very light in colour, but the heartwood frequently has a light reddish-brown tinge. The wood is rather difficult to work, shrinks very considerably in drying, but takes a smooth, hard surface in finishing. It is not particularly resistant to decay.

Typical Uses

Handles	Neck yokes
Vehicle spokes	Pike-poles
Chairs	Rims for wheels
Felloes	Sports goods
Turnery	Ladder rungs
Machinery parts	
Doubletrees and whippletrees	

IRONWOOD

Ostrya virginiana (Mill.) K. Koch

Only one species of ironwood occurs in Canada. It is sometimes called rough-barked ironwood and hornbeam, and is found from Nova Scotia to Ontario associated with beech, sugar maple, ash, and white elm. The tree is small, generally from 25 to 35 feet in height and 12 inches and under in diameter. It is therefore of little importance commercially, but on account of its great strength and hardness it is valued for a number of special uses. It ranks with hickory among the strongest woods in Canada, and is used for similar purposes. It weighs about 50 pounds per cubic foot, air-dry.

MAPLE

Acer

Besides the exotic species of maple grown for ornamental purposes, ten species are native to Canada but only five are of any commercial importance, namely, sugar maple, broadleaf maple, silver maple, red maple, and Manitoba maple.

Sugar Maple, *Acer saccharum* Marsh., frequently called hard maple or rock maple, is the chief commercial species of maple in Canada. It sometimes reaches a height of 125 feet and a diameter of 3 feet, but is, generally, 20 to 30 inches in diameter and 80 to 90 feet in height. Sugar maple is found from Nova Scotia to the Lake of the Woods, south of the height of land between Hudson Bay and the Great Lakes; in commercial size, however, its range is much more restricted. Next to yellow birch it is the most important commercial hardwood in Canada, judged on the basis of utility and availability.

The wood is light in colour, with little contrast between heartwood and sapwood; it is of a creamy white shade, though the heartwood may have a reddish tinge. Larger trees on certain sites occasionally develop a dark brown heart which detracts from the appearance of the wood. The annual rings are fairly well marked by a narrow brown line which gives the wood a pleasing figure when cut flat-grain.

Sugar maple is the hardest and heaviest of the more abundant Canadian commercial hardwoods, in these two respects surpassing yellow birch. Its weight in the air-dry condition is about 47 pounds per cubic foot. It has splendid resonance properties.

Considering its hardness, sugar maple works well, taking a fine, smooth surface and a high polish. It is an excellent wood for turnery, has good gluing properties, and holds nails and screws well, but, on account of its hardness, offers considerable difficulty

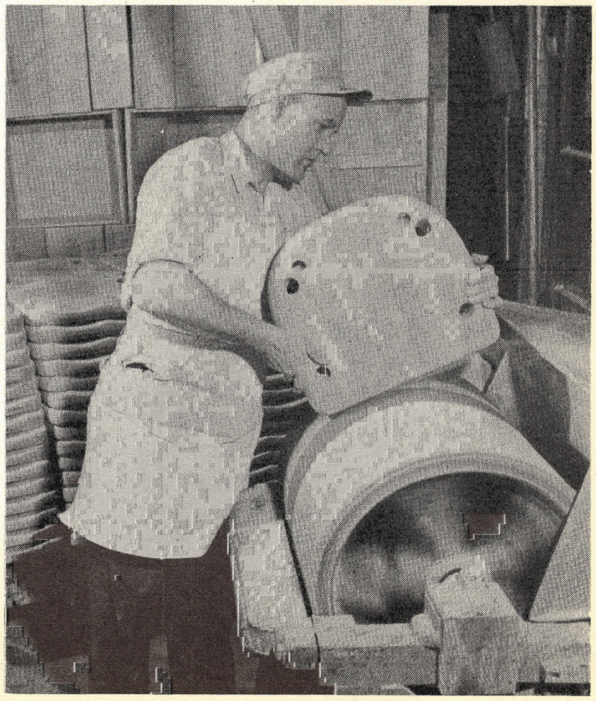


PLATE 9.—Drum Sanding.

in nailing. Sugar maple is easy to stain and takes enamel and paints satisfactorily. Curly maple and bird's-eye maple are particularly valued for furniture.

It is a very strong, stiff wood, exceeding white oak in these respects, and is therefore used extensively in frame and body work. When treated with preservative it is used for railway ties, but untreated maple is not durable in situations conducive to decay. It offers considerable resistance to penetration of preservatives, but by incising before treatment satisfactory penetration can be obtained.

Although sugar maple seasons slowly, with proper care it may be dried in the open or in dry-kilns without undue difficulty. Its shrinkage in seasoning is fairly high. For many purposes sugar maple and yellow birch are used in Canada without differentiation.

It is the principal source of maple syrup and maple sugar.

Typical Uses

Vehicle stock	Interior finish
Sporting goods	Butcher blocks
Furniture	Bowling alleys
Piano actions	Railway ties
Printing and press rolls	Shoe findings
Railway coach work	Turnery
Electrical apparatus	Musical instruments
Veneers and plywood	Small arms furnishings

Mangle rolls
Dairy and laundry appliances
Flooring (house, warehouse, public buildings)

Broadleaf Maple, *Acer macrophyllum* Pursh.—This species is also referred to as British Columbia maple, Oregon maple, and big-leaved maple. In Canada it is found only in British Columbia along the Pacific Coast and on the adjacent islands. On favourable sites it is from 60 to 90 feet in height and 1 foot to 2½ feet in diameter.

The wood is of a very light brown colour, has a fine uniform texture and a subdued and pleasing figure, and takes an excellent finish. It is more easily worked than sugar maple, but is not so heavy, hard, and strong. It takes stains well, has good gluing and nailing properties, and seasons readily with little de-grade. It weighs about 36 pounds per cubic foot, air-dry.

Typical Uses

Furniture	Panelling
Interior finish	Cabinet-work
Turnery	Sporting goods
Flooring	

Silver Maple, *Acer saccharinum* L.—This species is commonly known as soft maple and white maple. It is found in New Brunswick and through southern Quebec and Ontario, sometimes attaining a height of 125 feet and a diameter of 5 feet, though usually, in a forest stand, it is 80 to 90 feet in height and 2 to 3 feet in diameter.

The wood is light in colour and considerably softer, lighter, and weaker than sugar maple. It is also inferior in these respects to red maple and broadleaf maple. However, it is generally included with red maple as soft maple. Where hardness and strength are not of prime importance, it is often used for the same purposes as hard maple. It weighs about 34 pounds per cubic foot, air-dry.

Red Maple, *Acer rubrum* L.—Red maple is also called soft maple, swamp maple, and scarlet maple. In Canada it is found from Nova Scotia to the Lake of the Woods in Ontario. It is not so large as the silver maple, usually being from 50 to 75 feet in height and 2 to 3 feet in diameter. The wood is very similar to hard maple, but is not so hard, strong, or heavy as that species, though in these respects superior to silver maple. Its uses are practically the same as those of hard maple, and, except for most exacting requirements with respect to hardness and strength, they are not differentiated in commercial use. It weighs about 38 pounds per cubic foot, air-dry.

Manitoba Maple, *Acer Negundo* L.—This species is sometimes called box elder and ash-leaved maple. It is found principally in southern Manitoba and Saskatchewan, usually along streams and the margins of lakes. It occasionally attains a height of 75 feet and a diameter of 3 feet, but ordinarily is very much smaller.

The wood is light in colour, also in weight, and is quite soft and weak. In these respects it is comparable with some of the softwoods or with the very light hardwoods. It is very inferior to the other maples and is of commercial importance only locally, principally for boxes, crates, and rough construction purposes. It is used to some extent for cooperage, drawer bottoms, woodenware and similar uses. It weighs about 31 pounds per cubic foot, air-dry.

OAK

Quercus

Twelve species of oak are found in Canada. Several of these are so small in size or are found in such limited quantity that they are of no commercial importance. The total production of all species of oak in Canada is very small and not nearly sufficient to meet domestic requirements; the considerable quantity imported comes from the United States.

Canadian species of oak may be divided into two groups, (1) the white oak group, including the white, Garry, post, swamp white, bur, chinquapin, chestnut, and dwarf chinquapin oaks, and (2) the black or red oak group, including the black, red, pin, and scarlet species.

White Oak, *Quercus alba* L.—Of the first group, white oak is by far the most important and the only one of much commercial importance. It is found only in southern Quebec and southern Ontario, where it grows to a diameter of 2 to 4 feet and a height of 50 to 100 feet. The wood is light in colour, shading from a creamy white to a pale brown tinge. It is one of the heaviest of Canadian hardwoods, weighing 48 pounds per cubic foot, air-dry. It is very strong, being very similar to yellow birch in most strength properties, but inferior to sugar maple. It is very hard, and capable of withstanding heavy wear, as in flooring. It is, however, particularly noted for its toughness, and its ability to withstand suddenly applied loads, and also for its durability in positions favourable to decay.

White oak takes a smooth, hard finish. It has a

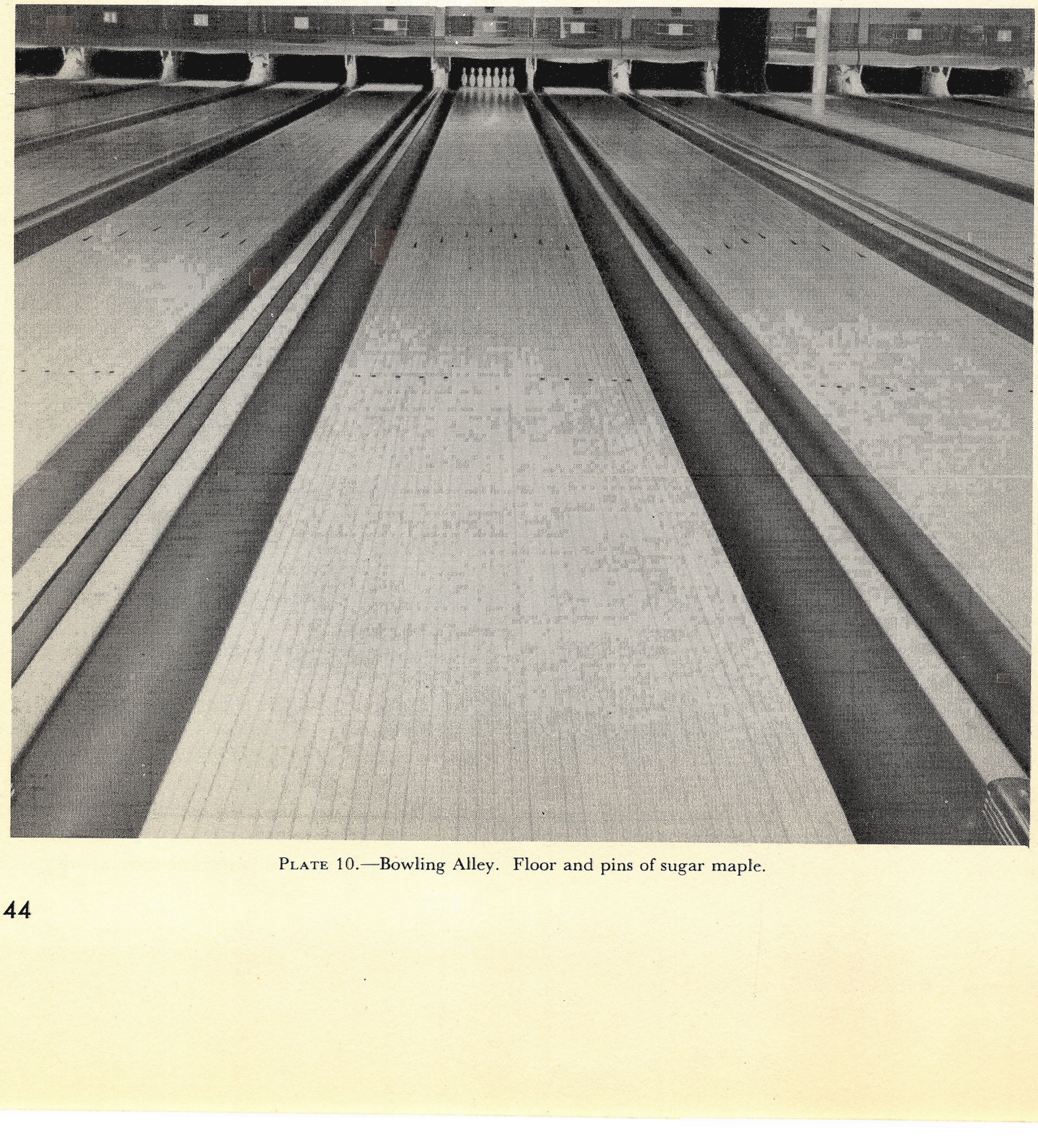


Plate 10.—Bowling Alley. Floor and pins of sugar maple.

particularly pleasing figure when quarter-sawn, which makes it valuable for interior finish, furniture, and cabinet-work. It is used more widely than any other wood in Canada for tight cooperage and particularly for containers for alcoholic liquors.

Its shrinkage in seasoning is moderate, but care must be exercised to prevent twisting and checking.

Typical Uses

Flooring	Agricultural implements
Interior finish	Tight cooperage
Cabinet-work	Furniture
Caskets	Pews and pulpits
Gymnasium equipment	Doors
Plywood and veneers	Counters
Railway-car construction	Boats
Wheel spokes	Vehicle stock
Ladder rungs	Machinery frames
Tanks (brewing and distilling)	

Red Oak, *Quercus borealis* Michx. f.—Red oak, the only species of the red oak group of significant commercial importance, is found more abundantly and over a wider range in Canada than white oak. It occurs from Cape Breton in Nova Scotia to Georgian Bay in Ontario, and occasionally along the north shore of Lake Huron and the east shore of Lake Superior, but not beyond the height of land separating the Great Lakes and Hudson Bay drainages. It is 60 to 70 feet in height and 2 to 3 feet in diameter, and is the most important species in the red or black oak group. The wood is, generally, not so fine in texture as white oak, nor is the figure when quarter-cut so pleasing. The wood is inclined to be darker in colour than white oak, sometimes approaching a reddish-brown tinge. Red oak is a hard, strong wood. It does not possess the durability for which white oak is noted.

It is used for similar purposes to white oak, but is not so highly valued for high-class work. It weighs about 43 pounds per cubic foot, air-dry.

POPLAR

Populus

Of the poplars, several species are also known as aspens or cottonwoods. Eight species of poplar are native to Canada, and several others have been introduced for ornamental purposes, for example, the Lombardy and silver poplars.

The poplars are very widely distributed in Canada, one or more species being found in every province. They vary greatly in size, several species being only 8 to 10 inches in diameter, whereas the black cottonwood of British Columbia may be 4 feet or over in diameter.

The wood of all the poplars is very similar. It is generally light in colour, varying from almost white to a greyish-white shade, light in weight, and quite soft. It is also comparatively weak and is not durable in exposed situations. It is inclined to warp and twist in seasoning unless care is taken in piling, but when properly seasoned it works well and takes a good finish. It has good painting properties, and takes and holds nails quite well. It is a good wood for boxes. It cuts well for veneer, some species when so cut being used for matches, and others for veneers and plywood.

Typical Uses

Soda pulp	Pails
Matches	Brush backs
Core-stock	Novelties
Boxes and crates	Veneers and plywood
Baskets	Drawer bottoms
Excelsior	
Fuelwood (Prairie Provinces)	

Trembling Aspen, *Populus tremuloides* Michx.—Other names applied to trembling aspen are white poplar, popple, and aspen poplar.

Trembling aspen is generally 8 to 12 inches in diameter and 50 to 60 feet in height, but occasionally attains a diameter of 24 inches and a height of 90 feet. It has a very wide distribution, extending from Newfoundland to the mouth of the Mackenzie River and Alaska. It usually occurs as a temporary type following fire, and is often associated with white birch or conifers such as pine, spruce, and true fir (balsam). A considerable amount of trembling aspen is cut for lumber, especially in the Prairie Provinces, in localities where other species are not plentiful. A great deal is also cut in the Prairie Provinces for fuel. Its use for matches, both in the domestic and export market, is increasing. It weighs about 28 pounds per cubic foot, air-dry.

Balsam Poplar, *Populus balsamifera* L.—This species is also called balm, black poplar, balm of Gilead, and,

in Quebec and the Maritime Provinces, tacamahac. Its distribution in Canada is very wide and very similar to that of trembling aspen. It is generally larger than aspen, attaining a height of 50 to 60 feet and a diameter of 1 to 2 feet, and on favourable sites may even attain a diameter of 3 feet and a height of 90 feet. The wood is very similar to that of trembling aspen, though the heartwood occasionally has a reddish-brown tinge. It weighs about 29 pounds per cubic foot, air-dry.

Eastern cottonwood, *Populus deltoides* Bartr.—The eastern cottonwood is one of the largest of the poplars, averaging 75 to 100 feet in height and 2 to 4 feet in diameter. It is generally found along the banks of streams and in rich bottom-land, where there is abundant moisture. In Eastern Canada it is found only in limited quantities, generally in small areas from Quebec westward through southern Ontario. In Western Canada it is found in the southern part of the Prairie Provinces. It weighs about 27 pounds per cubic foot, air-dry.

Black cottonwood, *Populus trichocarpa* Torr. & Gray.—This species is sometimes called balsam cottonwood, western balm, and cottonwood.

It is found from Alaska southward along the Pacific Coast and especially in the valley-bottoms of large rivers flowing into the Pacific Ocean, such as the Nass, Skeena, and Fraser Rivers. It is also found in some of the larger valleys of the southern interior of British Columbia. The black cottonwood is a large tree, 80 to 125 feet in height and 3 to 5 feet in diameter. It is the largest hardwood found in British Columbia and is there valued principally for the making of plywood. It is also used for soda-pulp, matches, excelsior, box lumber, and other similar purposes.

Largetooth aspen, *Populus grandidentata* Michx.—This species is sometimes called big-toothed poplar. In Canada, it is found from Nova Scotia and New Brunswick westward through Ontario and Quebec, south of the height of land between Hudson Bay and the Great Lakes.

Largetooth aspen grows to a height of 40 to 50 feet and a diameter of 1 foot to 2 feet. The wood is similar to that of trembling aspen and is used for like purposes.

CLASSIFIED USES OF CANADIAN WOODS†

by J. B. PRINCE††

WOOD is used so extensively, and for such a wide variety of purposes, that it is practically impossible to compile a complete list of all its industrial uses, showing in each case the species considered most suitable. So great, however, is the demand for information of this nature that an attempt has been made to indicate the more important species in general demand for specific purposes, or entering into the production of various commodities.

The choice of a wood for a particular use falls naturally into two categories; first, where the inherent characteristics of the material are of more importance than availability or cost; second, where availability or cost are the primary factors, the properties of the wood being secondary.

The lists which follow should not be interpreted as including all Canadian woods which may be or are being used for specific purposes, but rather as being those species considered most suitable. In so far as possible, where peculiar characteristics are important, woods are shown in the order of their desirability.

Imported exotic species and woods not usually available in commercial quantities in Canada are included when the qualities characteristic of these species are important for the proposed use. Species imported, with country of origin, are also shown separately at the end of the list.

When a generic name, such as spruce, is used, it is implied that all species of that genus are acceptable.

One asterisk indicates an exotic species frequently used in Canada. Two asterisks indicate a species native to Canada, but of which commercial supplies are chiefly imported.

Aircraft

FLOORING AND PLANKING
Spruce, White pine, Western white pine, Western red cedar.

LONGERONS
White ash, Spruce.

†Also exotic species when of commercial importance.

††In bringing this section up to date, extensive use has been made of the original material prepared by Mr. M. J. Brophy for the first edition.

PROPELLERS
Yellow birch, Mahogany*, Black walnut**.

REINFORCING, PACKING BLOCKS, ETC.
Rock elm, Sugar maple, White ash, Yellow birch.

RIBS, WEBS, CAP STRIPS, ETC.
Spruce, White pine, Basswood.

SKIS
Ash, Hickory, Yellow birch, Sugar maple.

VENEERS AND PLYWOOD
Yellow birch, White birch, Western white birch, Mahogany*, Sitka spruce, Red pine, Yellow poplar**, Basswood, Black cottonwood.

Agricultural Implements

(For Strength)
Hickory**, Oak, White ash, Elm, Birch, Sugar maple, Beech, Ironwood.

(For Utility)
Pine, Douglas fir, Spruce, Western hemlock, Western larch, Basswood.

Artificial Limbs
Willow.

Barrels

APPLE, FISH, FLOUR, SUGAR (See "Container—Cooperage—Slack")

FISH, OIL, VINEGAR (See "Container—Cooperage—Tight")

MALT LIQUORS, SPIRITS, WINE (See "Container—Cooperage—Tight")

Baskets (See *"Containers"*)

Battery Separators
Yellow cedar, Basswood, Douglas fir.

Bearings
Lignum vitae*, Sugar maple.

Beekeepers' Supplies
White pine, Basswood, Poplar, Spruce.

Bent Goods
Hickory, White oak, White ash, Elm.

Blinds, Venetian
White pine, Western white pine, Basswood, Yellow cedar.

Boats (See *"Ships and Boats"*)

Bobbins, Shuttles, Spools, etc.
Dogwood**, Sugar maple, Yellow birch, White oak, White ash**, Beech, Hickory**

Bodies and Boxes, Auto and Truck
Douglas fir, Sugar maple, Yellow birch, Red pine.

Boot and Shoe Findings
Sugar maple.

Bread Boards
Spruce, Sugar maple.

Brush Blocks
Black walnut**, Yellow birch.

Buildings, Framework (See *"Construction"*)

Butcher Blocks
Sugar maple, Yellow birch, Beech.

Cabinet-work (See *"Furniture"*)

Canoes (See *"Ships and Boats"*)

Carvings
White pine, Western white pine, Basswood, White birch, Yellow cedar.

Caskets and Coffins
Mahogany*, Black walnut**, Yellow birch, White pine, Western white pine, Spruce, Basswood, Ash, Soft elm, Oak, Sugar maple, Broadleaf maple, Beech, Cedar, Western red cedar, Chestnut**, Black cherry**, Cypress*, Yellow cedar, Douglas fir.

Churns
White pine, Douglas fir, Cypress*, Redwood*.

Cloth Boards
Basswood, White pine.

Clothes Pins (See *"Laundry Supplies"*)

Conduits (See *"Pipes"*)

Concrete Forms (See *"Construction"*)

Construction

BUILDINGS, General Scaffolding
Spruce, Douglas fir, Western hemlock, Fir (true), Eastern hemlock, Western larch, Pine, Tamarack.

BUILDINGS, Framework, Light Structural
Spruce, Douglas fir, Pine, Western hemlock, Eastern hemlock, Fir (true), Western larch, Tamarack, Western red cedar.

BUILDINGS, Framework, Heavy Structural
Douglas fir, Pine, Spruce, Hemlock, Western larch, Western red cedar.

CONCRETE FORMS
Spruce, Douglas fir, Western hemlock, Eastern hemlock, Pine, Western larch, Fir, (true), Tamarack, Western red cedar.

DOCKS, WHARVES, POSTS, PILING, DOORS, CRIBWORK—(*See "Piling", "Cribwork", "Stringers"*)

DOORS
Oak, Black cherry, White pine, Western white pine, Western red cedar, Douglas fir, Ponderosa pine, Yellow birch, Maple, Spruce, Western hemlock, Western larch.

FENCING
Spruce, Pine, Western red cedar, Eastern white cedar, Douglas fir, Eastern hemlock, Western hemlock, Tamarack, Western larch.

FENDERS
Rock elm, Douglas fir, Western larch, Eastern hemlock, Tamarack.

FLOORING (*Light*)
White oak, Red oak, Sugar maple, Yellow birch, Beech, Douglas fir, Western hemlock, Western larch, Red pine, Ponderosa pine, Soft maple, White birch, Spruce

FLOORING (*Heavy*)
Oak, Sugar maple, Yellow birch, Beech, Douglas fir, Tamarack, Western hemlock, Eastern hemlock, Western larch, Red pine.

HIGHWAY BRIDGES, POSTS, COLUMNS, SILLS, ETC.
Douglas fir, Western larch, Tamarack, Eastern white cedar, Western red cedar, Eastern hemlock, Western hemlock, Red pine, Ponderosa pine.

HIGHWAY CULVERTS, DRAINS
Western red cedar, Eastern white cedar, Douglas fir, Western larch, Eastern hemlock, Tamarack.

INTERIOR FINISH AND WOODWORK
Oak, Basswood, Chestnut, Butternut, Western white birch, Yellow birch, Douglas fir, White pine, Western red cedar, Western hemlock, Western larch, Western white pine, Spruce, Red pine, Ponderosa pine.

LATH
Pine, Douglas fir, Western red cedar, Spruce, Western hemlock, Western larch.

MACHINERY (*Steam Shovels, Dredges, etc.*)
Douglas fir, Oak, Red pine, Sugar maple, Hemlock, Ash, Yellow birch, Chestnut**, Spruce, Elm, Beech.

PILING, CRIBWORK, STRINGERS
Douglas fir, Red pine, Tamarack, Western larch, Western hemlock, Eastern hemlock, Jack pine, Lodgepole pine, Western red cedar, Eastern white cedar, Yellow cedar, Spruce, Hardwoods (occasionally).

PLANKING
Yellow birch, Sugar maple, Douglas fir, Red pine, Eastern hemlock, Western hemlock, Western larch, Beech, Spruce, Western red cedar.

RAFTERS, ROOF PLANKING
Pine, Douglas fir, Spruce, Eastern hemlock, Western hemlock, Western red cedar, Western larch.

SIDING AND EXTERIOR TRIM
Western red cedar, White pine, Western white pine, Douglas fir, Western hemlock, Red pine, Ponderosa pine, Eastern hemlock, Spruce, Western larch.

SILLS, UNTREATED
Western red cedar, Eastern white cedar, Western hemlock, Eastern hemlock, Douglas fir, Western larch.

SHEATHING AND SUB-FLOORING
Douglas fir, Hemlock, Pine, Spruce, Fir (true), Western larch.

SHINGLES
Western red cedar, Eastern white cedar, White pine, Eastern hemlock.

STRUCTURAL TIMBERS
Douglas fir, Spruce, Red pine, Western hemlock, Western larch, Eastern hemlock.

TRUSS MEMBERS, FLOOR BEAMS, AND STRINGERS
Douglas fir, Western larch, Tamarack, Western hemlock, Eastern hemlock, Red pine.

WINDOWS, DOOR PANELS, AND WINDOW SASH
White pine, Western white pine, Red pine,

Ponderosa pine, Douglas fir, Western red cedar, Western larch.

Containers

(*Species Commonly Used*)

Spruce, Pine, Hemlock, Douglas fir, Fir (true), Basswood, Larch, Poplar, Maple, Beech.

BASKETS

Birch, Soft elm, Basswood, Sitka spruce, Ash.

BOXES, Ammunition

Spruce, White pine, Yellow birch. (Other species are sometimes used, but specifications always indicate the species)

BOXES, Apple, Berry (Species commonly used for containers)

BOXES, Butter

Spruce, Fir (true), Western hemlock, Poplar.

BOXES, Cheese (*Drums*)

(Species commonly used for containers)

BOXES, Cigar

Spanish cedar*, Yellow poplar**, Redwood*, Western red cedar, Basswood.

BOXES, Veneer and Plywood

Birch, Douglas fir, Basswood, Poplar.

CASKS, Fish (*See list for tight or slack cooperage as required*)

CASKS, Malt liquors, spirits, wines

White oak**.

CISTERNS (*See listing below for tight cooperage*)

COOPERAGE

(*Species for tight cooperage staves*)

White oak, Soft elm, Yellow birch, Douglas fir, White ash, Soft maple, Basswood.

(*Species for slack cooperage staves*)

Elm, Spruce, Douglas fir, Soft maple, Oak, Pine, Hemlock, Balsam fir, Poplar, Ash.

(*Heading—slack and tight cooperage*)

Oak, Soft elm, Yellow birch, Douglas fir, White ash, Soft maple, Basswood.

(*Hoops*)

White ash.

(*Bungs*)

Yellow poplar**, Spruce, Basswood, White pine.

KEGS, Malt liquors, spirits, wines

White oak**.

KEGS, Nail (*See slack cooperage species above*)

LAUNDRY PAILS AND TUBS

Cypress*, Cedar, Douglas fir.

SILOS

Douglas fir, Spruce, Pine, Western hemlock,

TANKS, Acid

Douglas fir, Pine, White oak**, Chestnut**.

TANKS, Water

Douglas fir, Western red cedar, Red Pine, Ponderosa pine, White pine, Western white pine, Eastern white cedar, Western larch, Tamarack, Oak, Chestnut**.

Core Stock

Yellow poplar**, Chestnut**, Poplar Spruce, Douglas fir, Western red cedar, Western hemlock, Birch, Red alder.

Cross-arms

Douglas fir, Red pine, Oak, Jack pine, Western hemlock, Western larch.

Depressors, Tongue

White birch.

Distillation, Hardwood

Yellow birch, White birch, Sugar maple, Soft Maple, Beech.

Docks, Wharves, Posts, Piling, Cribwork (See *"Construction"*)

Doors (See *"Construction"*)

Dough Mixers

Sugar maple, Yellow birch.

Dowels

Birch, Maple, Ash, Oak, Beech, Douglas fir, Elm, Hickory**, Red pine.

Electrical Apparatus

Sugar maple, Yellow birch, Beech, Oak, Soft elm, Red pine, Basswood, Western red cedar, Spruce, Black walnut*, Western larch, Douglas fir.

INSULATING PINS

Black locust*, Sugar maple, Yellow birch, Oak, Ash.

Excelsior (*Wood-wool*)

Poplar, Basswood, White pine.

Fish-net Floats

Eastern white cedar, Western red cedar.

Flooring (See *"Construction"*)

Furniture

GENERAL (*Decorative Types*)

Mahogany*, Black walnut**, Black cherry**, Oak, Sugar maple, Yellow birch, Butternut, Elm.

GENERAL (*Utility and Secondary Types*)

White ash, Douglas fir, Basswood, Western white pine, Red pine, Spruce, Western red cedar, Poplar, Western hemlock, Western white birch, Broadleaf maple, Red alder.

CABINET WORK (*Radio, Gramophone, Show-case, etc.*)

Black walnut**, Mahogany*, Yellow birch, Sugar maple, Oak, White pine, Basswood.

CHESTS

(*Red juniper and cedar preferred for moth-resistant chests*)

Black walnut**, Mahogany*, Red juniper**, Yellow poplar**, Basswood, Poplar, Eastern white cedar, Western red cedar, Yellow cedar.

Greenhouses

White pine, Western white pine, Western red cedar, Eastern white cedar, Yellow cedar, Douglas fir.

Gun Stocks

Black walnut**, Yellow birch, Sugar maple.

Handles

AXE

Hickory**, Rock elm, White ash, Ironwood, Sugar maple.

BROOM

Sugar maple, Birch, Beech, Western hemlock, Douglas fir, Red pine.

BRUSH

Black walnut**, Birch, Sugar maple, Broadleaf maple, Beech, Basswood, Poplar.

SCYTHE

Soft elm.

SHOVEL

White ash, Ironwood, Birch, White elm, Oak, Maple.

TOOL

Hickory**, White ash, Apple, Rock elm, Soft elm, Ironwood, Sugar maple, Birch, Black cherry**.

Hat Blocks

White pine, Western white pine, Basswood, White birch.

Heels (See *"Boot and Shoe Findings"*)

Hubs (See *"Vehicles, Horse-Drawn"*)

Insulating and Building Board

Pulp and paper screenings and shavings.

Insulating Pins and Brackets (See *"Electrical Apparatus"*)

Insulation

Sawdust, Shavings.

Interior Finish and Woodwork (See *"Construction"*)

Ironing Boards

Basswood, White pine, Western white pine, Douglas fir, Spruce.

Kegs (See *"Containers"*)

Knees (See *"Ships and Boats"*)

Ladders

RUNGS

Elm, Yellow birch, Sugar maple, Oak, Beech, Hickory**, Douglas fir.

STRINGERS

Spruce, Douglas fir, Western hemlock, Ponderosa pine, Red pine.

Lamps and Shades (See *"Furniture"*)

Last Blocks (See *"Boot and Shoe Findings"*)

Lath (See *"Construction"*)

Laundry Appliances

PINS

Birch, Sugar maple, Basswood.

TUBS

Cypress*, Cedar, Douglas fir.

Matches

Western white pine, White pine, Poplar, Basswood.

Mine Timbers†

Spruce, Jack pine, Lodgepole pine, Red pine, Elm, Douglas fir, Western hemlock, Western larch, Tamarack, Western red cedar, Eastern white cedar, Yellow birch, Sugar maple, Oak, Beech.

Musical Instruments

(*Decorative Value*)

Rosewood*, Mahogany*, Black walnut**, Ebony*, Oak, Sugar maple—particularly bird's-eye.

(*Hardness*)

Lemonwood*, Sugar maple.

PIANOS AND ORGANS (See "Decorative" group above)

RADIOS AND GRAMOPHONES (See "Furniture—Cabinet-work")

SOUNDING BOARDS

Spruce.

(*Utility and Secondary Uses*)

Chestnut**, Basswood, Yellow birch, Western white pine, White pine, Douglas fir, Soft elm, Hickory**, Western red cedar.

VIOLINS, Bows

Brazilwood*, Ebony*.

VIOLINS, Sound Box

Spruce, Sugar maple, Western red cedar.

Oars and Paddles (See *"Ships and Boats"*)

Pails and Tubs (See *"Containers—Cooperage"*)

Patterns and Models

White pine, Western white pine, Ponderosa pine, Red pine, Yellow cedar, Western red cedar, Black cherry**, Mahogany*, Basswood.

Paving Blocks

Douglas fir, Red pine, Western larch, Tamarack.

Pencils

Red juniper, Port Orford cedar*, Incense cedar*, Eastern white cedar, Western red cedar.

†Availability and price are important factors – sometimes the elastic qualities peculiar to certain species, e.g., spruce, are desirable; in locations favourable to decay species that are naturally resistant or those that can be readily treated with preservatives are preferred.

Picture and Mirror Moulding and Framing

White pine, Basswood, Western white pine, Yellow cedar, Western red cedar, Black cherry**, Chestnut**, Mahogany*, Yellow birch, Soft maple, Oak, Black walnut**, Broadleaf maple, Red alder.

Pipes *(Conduits)*, Flumes, etc.

Douglas fir, Western red cedar, Eastern white cedar, Western larch, Red pine, Ponderosa pine.

Plumbers' Supplies *(Toilet Seats)*

Yellow birch, Ash, Elm, Sugar maple, Oak, Pine, Black walnut**, Birch, Chestnut**, Black cherry**.

Poles, Telephone and Telegraph (See *also "Cross-arms and Top-pins"*)

Western red cedar, Eastern white cedar, Red pine, Jack pine, Lodgepole pine, Douglas fir, Western hemlock, Tamarack, Western larch, Ponderosa pine.

Pulley Blocks

Sugar maple, Yellow birch, Beech, Basswood, Elm.

Pulp

MECHANICAL

Spruce, Fir (true), Jack pine, Western hemlock, Eastern hemlock.

SODA

Poplar, White birch, Soft maple.

SULPHATE

Jack pine, Spruce, Fir, Douglas fir, Western red cedar, Lodgepole pine, Birch, Maple, Poplar.

SULPHITE

Spruce, Fir, Western hemlock, Eastern hemlock, Jack pine.

Plywood (See *"Veneers and Plywood"*)

Rafters and Roof Planking (See *"Construction"*)

Refrigerators

Cypress*, White oak, Eastern white cedar, Western red cedar.

Rollers, Window Shade

White pine, Red pine, Basswood.

Rules (See *"Scientific Instruments"*)

Sash ***(See Construction—"Window, door panels, and window sash")***

Scaffolding ***(See "Construction—Buildings, general scaffolding")***†

Scientific Instruments

Sugar maple, Yellow birch, Beech, White pine, Basswood, Western red cedar, Eastern cedar, Hickory**, White ash, Yellow cedar. Oak, Spruce, Black walnut**, Black cherry**, Chestnut**, Elm.

RULES

Boxwood*, Sugar maple, Yellow birch.

Scythe Snaths ***(See "Handles")***

Sewing Machines

Yellow birch, Sugar maple, Soft elm, Ash, Black walnut**, Chestnut**.

Shade and Map Rollers

White pine, Red pine, Basswood, Birch, Douglas fir, Maple, Spruce, Beech.

Sheathing and Sub-flooring ***(See "Construction")***

Shells and Rough Boxes ***(See "Caskets and Coffins")***

Shingles ***(See "Construction")***

Ships and Boats

DECKING

Teak*, Western white pine, Western red cedar, Chestnut**, Oak, Douglas fir, Sugar maple, Birch, Western hemlock.

FRAME AND KEEL

Douglas fir, Oak, Hickory**, White oak, Tamarack, Yellow cedar.

KNEES

Oak, Tamarack.

OARS AND PADDLES

White ash, Spruce, Sugar maple.

PLANKING

Eastern white cedar, Western red cedar, Yellow cedar, Red pine, Tamarack, Spruce, Western hemlock, Douglas fir, Oak, Chestnut**, Sugar maple, Birch.

RIBS AND BRACES (*Canoe*)

Ash, Hickory**, Elm, Yellow cedar, Eastern white cedar, Western red cedar, Spruce.

†Spruce is considered most desirable owing to its elastic properties.

Shuttles ***(See "Bobbins")***

Siding and Exterior Trim ***(See "Construction")***

Signs ***(Advertising)***

Pine, Basswood, Spruce, Western red cedar, Douglas fir, Western hemlock, Fir.

Sills—Untreated ***(See "Construction")***

Silos ***(See "Containers—Cooperage")***

Skis, Aircraft ***(See "Aircraft")***

Skis, Sporting ***(See "Sporting Goods")***

Sleighs ***(See "Vehicles, Horse-drawn")***

Snow Fencing ***(See "Lath")***

Spinning Wheels

Maple, Birch.

Spoolwood

White birch.

Spools ***(See "Bobbins, etc.")***

Spoons ***(See "Woodenware")***

Sporting Goods

ARCHERY, Arrows

Port Orford cedar*, Yellow cedar, Eastern white cedar, Western red cedar, Sugar maple (footing).

ARCHERY, Bows

Lemonwood*, Western yew, Osage orange*, Serviceberry (lancewood), Hickory**, White ash.

BASEBALL BATS

Hickory**, White ash, Sugar maple, Willow.

BILLIARD TABLES

Sugar maple, Yellow birch, Black walnut**, Mahogany*, Elm, Oak.

BOWLING PINS

Sugar maple.

CRICKET BATS

Willow.

FISHING RODS

Greenheart*, Serviceberry (lancewood), Bamboo*.

GOLF CLUBS, Heads

Persimmon*, Sugar maple.

GOLF CLUBS, Shafts

Hickory**, White ash, Sugar maple.

HOCKEY STICKS

Rock elm, White elm, White ash, Yellow birch.

LACROSSE STICKS

Hickory**.

SKIS

White ash, Hickory**, Sugar maple, Yellow birch.

TENNIS AND BADMINTON RACQUETS

White ash, Western red cedar, Hickory**, Oak, Basswood.

Staves (See *"Cooperage"*)

Stocking Dryers

Maple, Birch.

Storage Battery Separators (See *"Battery Separators"*)

Structural Timbers (See *"Construction"*)

Tackle Blocks (See *"Pulley-blocks"*)

Tanks (See *"Containers—Cooperage"*)

Tannin

Quebracho*, Chestnut**, Eastern hemlock (bark), Western hemlock (bark), Oak, (bark)

Tie Plates

Yellow birch.

Tie Plugs

All species.

Toys and Novelties

Maple, Birch, White pine.

Trays (See *"Furniture—Decorative Types"*)

Trees (See *"Boot and Shoe Findings"*)

Vehicles, Horse-drawn

HUBS

White oak**, Hickory**, Rock elm, Ironwood, Yellow birch, Sugar maple.

GENERAL CONSTRUCTION

Hickory**, Ash, Elm, Oak, Ironwood, Sugar maple, Beech, Yellow birch.

MINOR AND SECONDARY USES

Douglas fir, White pine, Red pine, Eastern hemlock, Western hemlock.

Veneers and Plywood

HARDWOOD

Yellow birch, White birch, Western white birch, Elm, Sugar maple, Basswood, Poplar, Mahogany*, Gaboon*.

SOFTWOOD

Douglas fir, Red pine, Western red cedar, Sitka spruce, Western hemlock.

Wagons (See *"Vehicles, Horse-drawn"*)

Wheels, Carriage and Wagon (See *"Vehicles, Horse-drawn"*)

Window Shade Rollers (See *"Rollers, Window Shade"*)

Window and Door Frames, Sash (See *"Construction"*)

Wood Flour

Pine, Spruce, Fir (true).

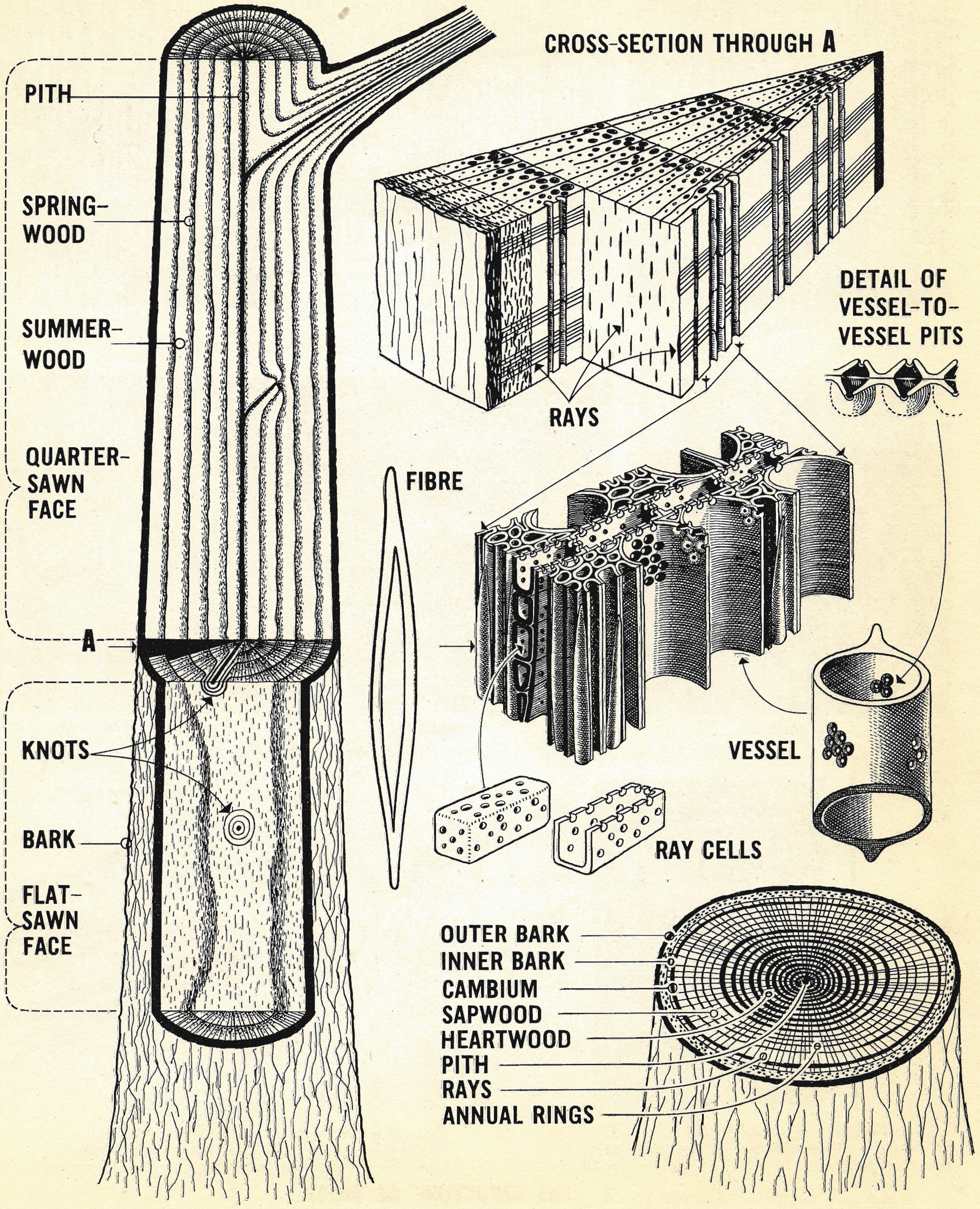
Wood Turning (See *"Bobbins, etc."*)

IMPORTED SPECIES AND COUNTRY OF ORIGIN

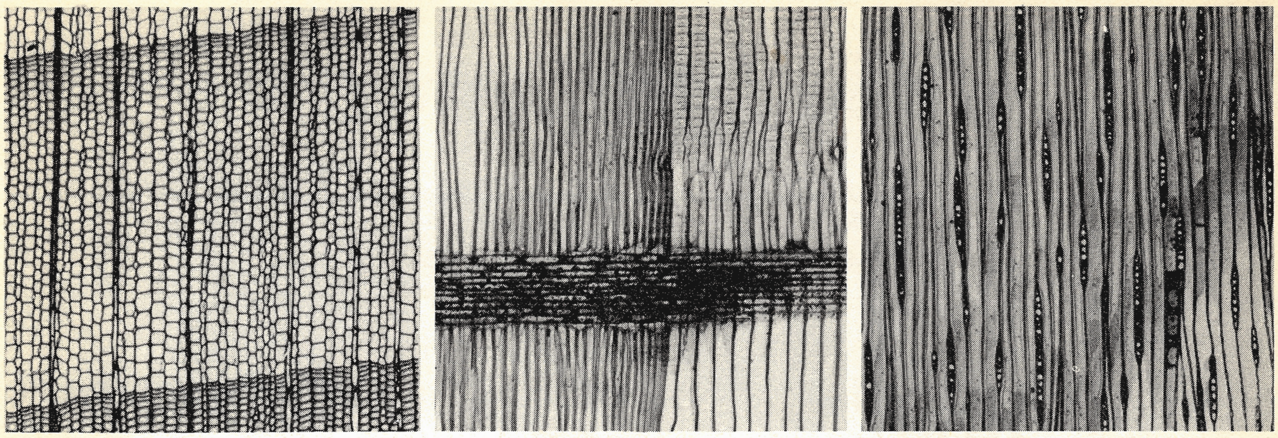
Bamboo	(*Bambuseae* spp.)	Tropics and sub-tropics
Black cherry	(*Prunus serotina*)	United States of America
Black locust	(*Robinia Pseudoacacia*)	United States of America
Black walnut	(*Juglans nigra*)	United States of America
Boxwood (genuine)	(*Buxus sempervirens*)	S. Europe, W. Asia, N. Africa
Brazilwood	(*Caesalpinia* spp.)	Brazil
Chestnut	(*Castanea dentata*)	United States of America
Cypress	(*Taxodium distichum*)	United States of America
Dogwood	(*Cornus* spp.)	United States of America
Ebony	(*Diospyros* spp.)	Tropical regions
Gaboon	(*Aucoumea klaineana*)	Gaboon, W. Congo

Greenheart	(*Ocotea rodiaei*)	British Guiana
Hickory	(*Carya* spp.)	United States of America
Lemonwood	(*Calycophyllum candidissimum*)	Central America
Lignum vitae	(*Guaiacum officiale*)	Central America
Mahogany	(*Swietenia* spp.)	Central America
Osage orange	(*Maclura pomifera*)	United States of America
Persimmon	(*Diospyros virginiana*)	United States of America
Port Orford cedar	(*Chamaecyparis Lawsoniana*)	United States of America
Quebracho	(*Aspidosperma* spp.)	Brazil, Argentina
Red juniper	(*Juniperus virginiana*)	United States of America
Redwood	(*Sequoia sempervirens*)	United States of America
Teak	(*Tectona grandis*)	Burma, Thailand
White ash	(*Fraxinus* spp.)	United States of America
White oak	(*Quercus alba*)	United States of America
Yellow poplar	(*Liriodendron tulipifera*)	United States of America

West Coast Dug-out Canoe.

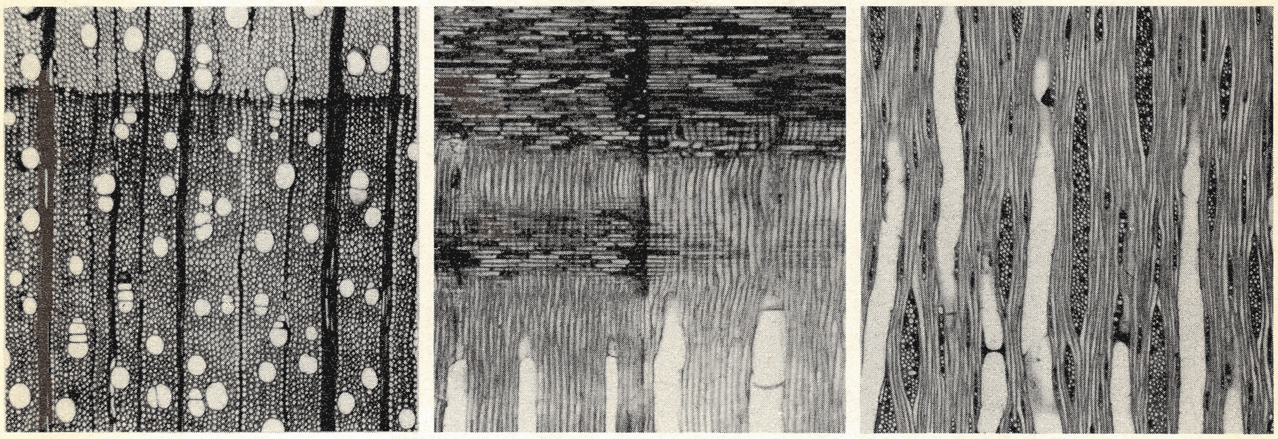


THE STRUCTURE OF WOOD



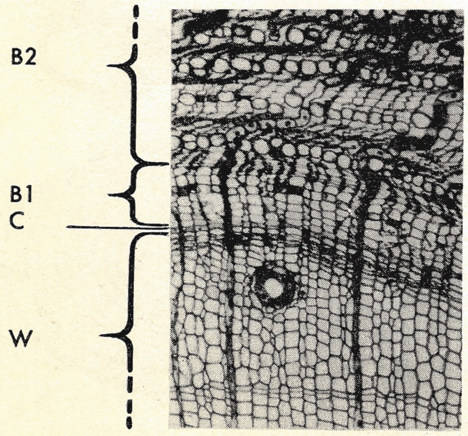
Transverse Radial Tangential

Western hemlock —*Tsuga heterophylla* (Raf.) Sarg. Wood sections × 50

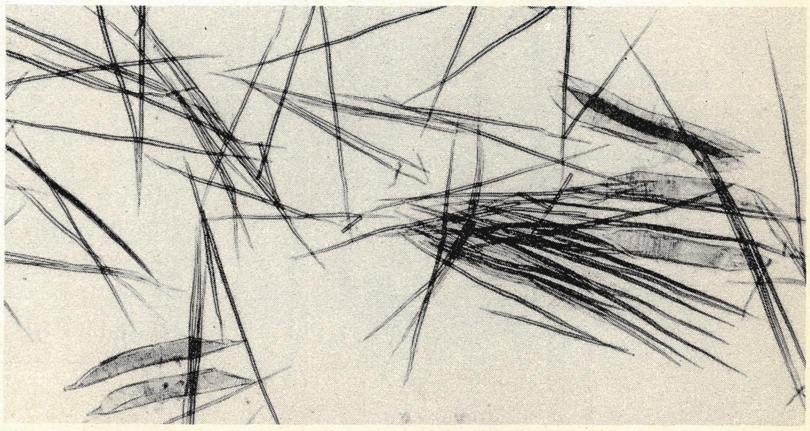


Transverse Radial Tangential

Sugar maple — *Acer saccharum* Marsh. Wood sections × 50



White pine (*Pinus Strobus* L.)
W—wood C—cambium B1—inner bark,
B2—collapsed bark. Transverse × 50



Cells of white birch (*Betula papyrifera* Marsh.) × 25. Wood was placed in acid which attacks cementing bond thereby allowing the component cells to separate.

THE STRUCTURE OF WOOD

THE STRUCTURE OF WOOD

by J. D. HALE

Variations in Properties of Wood Caused by Structural Differences

WOODS are ordinarily known by their common, rather than their botanical names. The species or kinds of wood are many, differing in colour, odour, ornamental characteristics, weight, and mechanical properties.

Aside from variations in colour and general appearance, one of the most obvious of the differences among woods is the difference in weight. One of the lightest woods may weigh as little as 6 pounds per cubic foot when air-dry, whereas the heaviest weigh 12 to 14 times as much. This represents the extreme range of variation likely to be found, and the great majority of woods employed for ordinary purposes weigh between 20 and 50 pounds per cubic foot, in air-dry condition.

Notwithstanding such differences in the density of various species, wood is remarkably uniform in that chemical analysis shows that most woods are fundamentally composed of the same substances. The fact that wood weighing 50 pounds per cubic foot is chemically the same as wood only half as heavy is explained by differences in the structural arrangement of the wood substance. Woods are composed of tiny cells packed so tightly together that they constitute a kind of honeycomb structure which can be seen, with the aid of a magnifier, on a surface cleanly cut across the trunk or branch of a tree. The thickness of the walls of these cells determines the density of the wood, so that woods characterized by thin-walled cells are of relatively light weight and those with thick-walled cells are heavy.

The fact that in pieces of equal dimensions and similar chemical nature there is, nevertheless, twice as much material in the wood weighing 50 pounds per cubic foot as in one weighing 25 pounds indicates important differences in the arrangement of the wood substance in the two specimens. In actual use, the heavier piece might support twice the load that the lighter one could bear. It is evident, therefore, that the different ways in which the elements of wood are arranged must have an important bearing on the uses to which woods are adapted, and it will be of advantage to users of wood to consider the important aspects of wood structure on which the properties and, consequently, the uses of different woods depend.

CHARACTERISTIC STRUCTURE OF WOOD

WOODS are grouped into two general classes, commonly called "softwoods" and "hardwoods". These terms are not entirely accurate, since some softwoods are actually harder than some of the hardwoods. The structure of the wood, however, is typical for each of these two classes, and is responsible for such differences in physical properties as generally distinguish the two groups and adapt them for different purposes. Botanically, the so-called softwoods are conifers, classified in a group called Gymnosperms, a term which broadly signifies plants

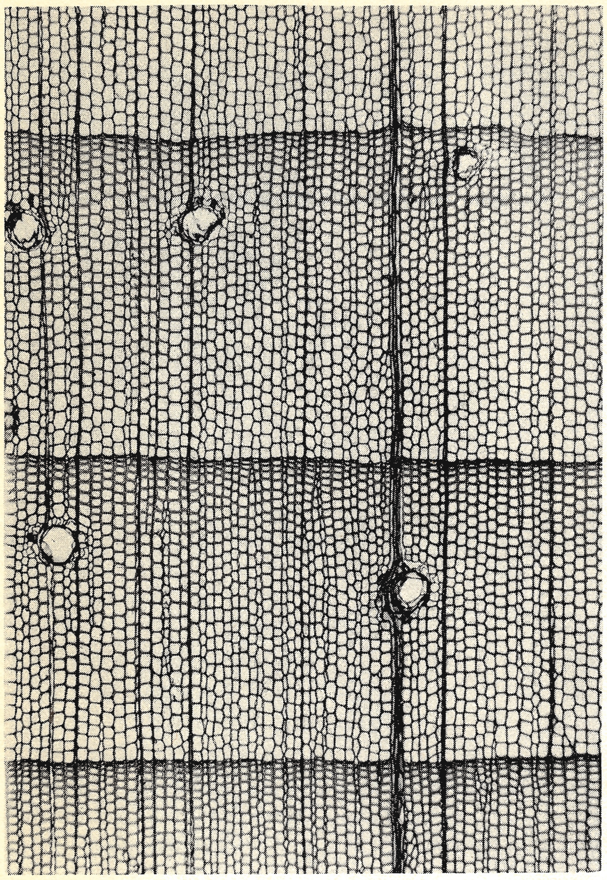


PLATE 11.—Transverse Section of White Pine (× 30).

The uniform, open structure accounts for the ease with which this wood may be carved and worked, and for its small degree of shrinkage.

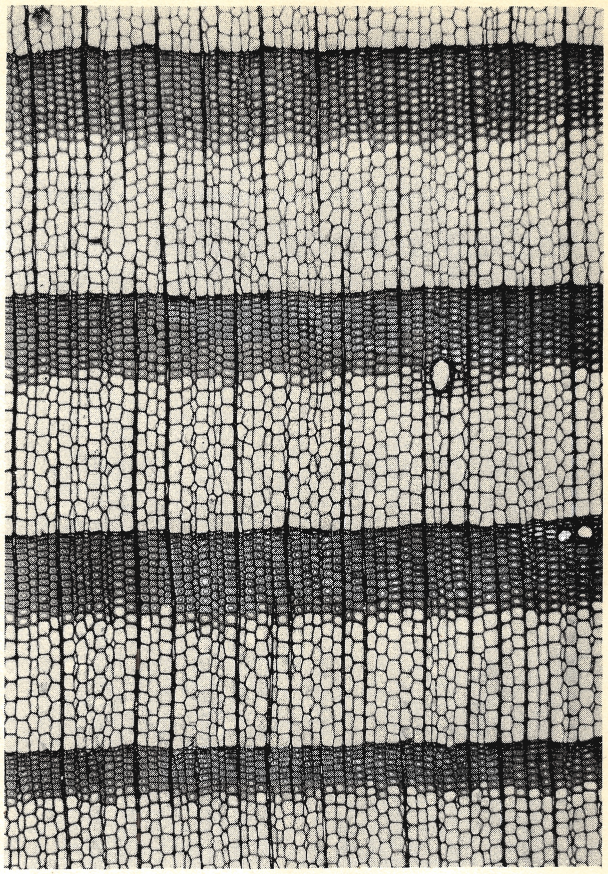


PLATE 12.—Transverse Section of Western Larch (× 30).

The thick-walled cells in the conspicuous "summer-wood" of western larch make it one of the heaviest and strongest of softwoods.

bearing exposed seeds, which are usually in cones. The pines and spruces are well-known examples of this group. The other botanical group, comprising the various orders of hardwoods, consists of the Angiosperms, which have true flowers, in the popular sense, and seeds enclosed in a fruit. All the Canadian softwoods have needle-like or scale-like leaves, which, except in the larches, persist throughout the winter. The broad leaves of Canadian hardwoods, on the other hand, are deciduous, although in certain cases the dead leaves remain on the tree for considerable periods before falling.

The Formation and General Appearance of Wood

The young shoot which a tree seed sends up when it germinates under favourable conditions forms a layer of wood around a soft central core of pith. Trees with an ancestry developed in the temperate latitudes, where periods of growth alternate with the winter resting periods, form each year a more or less definite layer of wood outside the wood previously formed. This concentric arrangement is visible on the ends of logs of most of the common kinds of such timber.

Red pine, spruce, and Douglas fir are examples of softwoods that show their general structural details clearly. The layered structure of the wood is distinguishable on the ends of logs of these species, from the largest outermost growth-ring to the smallest circle marking the first year of growth at the centre. The fact that each of these distinct layers consists generally of the wood added during one year has given them the name "annual layers" or "annual rings".

In healthy trees, the outside layers of wood are usually yellowish or creamy white in colour, often sharply distinguished from a definitely darker region called the "heartwood" at the central portion of the log. The light-coloured outer band of wood is known as sapwood, and may be composed of many years' growth, its thickness depending in general on the age of the tree, the species, and the rate of growth. In the spruces of Eastern Canada, however, the heartwood has the same light colour as the sapwood. At the middle of the log, in the centre of the innermost annual layer, is a core of soft tissue, usually brownish in colour, called the pith. This may be very fine and inconspicuous, or may be a quarter of an inch or more in diameter.

The successive layers are deposited on the surface of the previously formed wood through the agency of a layer of living tissue, called the cambium, situated between the wood and the bark. The cambium envelops the wood of trunk and branches in a close-fitting film. From the inner surface of the cambium is deposited new wood which increases the volume of the tree. Each year a layer of wood is deposited outside the previous wood of trunk and branch by this tissue, which at the same time generates the bark from its outer surface.

The layers of wood, when first formed, are light-coloured, and, as sapwood, function as conductors of sap, which is chiefly water derived through the roots from the soil. Sap is conducted upward to the leaves where, from the gases of the air and the energy of the sun's rays, food is manufactured and conveyed downward through the inner bark to the live tissue enveloping the wood, where the food is

Plate 13.—Transverse Section of Yellow Birch (× 30).

A diffuse-porous wood of uniform texture

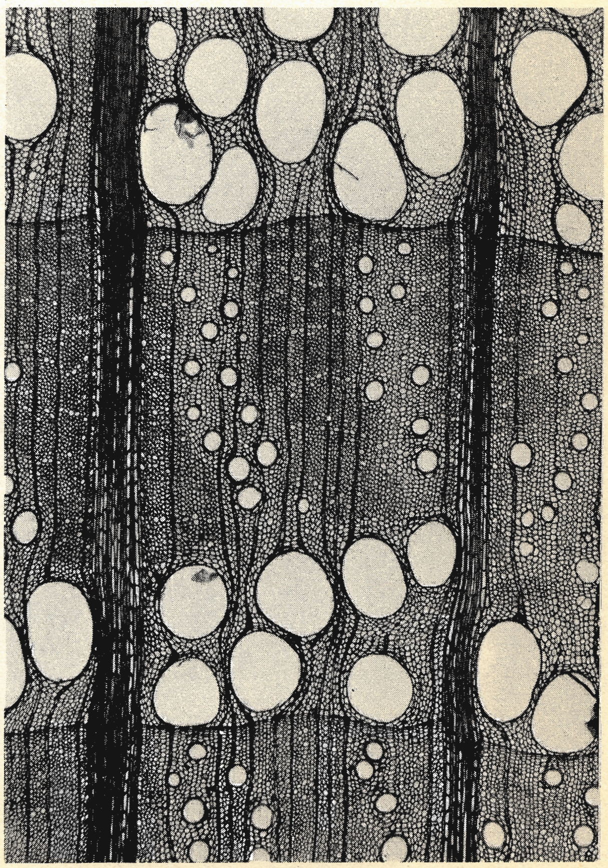


Plate 14.—Transverse Section of Red Oak (× 30).

This illustrates the arrangement of pores in ring-porous woods. Note that two of the broad rays characteristic of the oaks are visible.

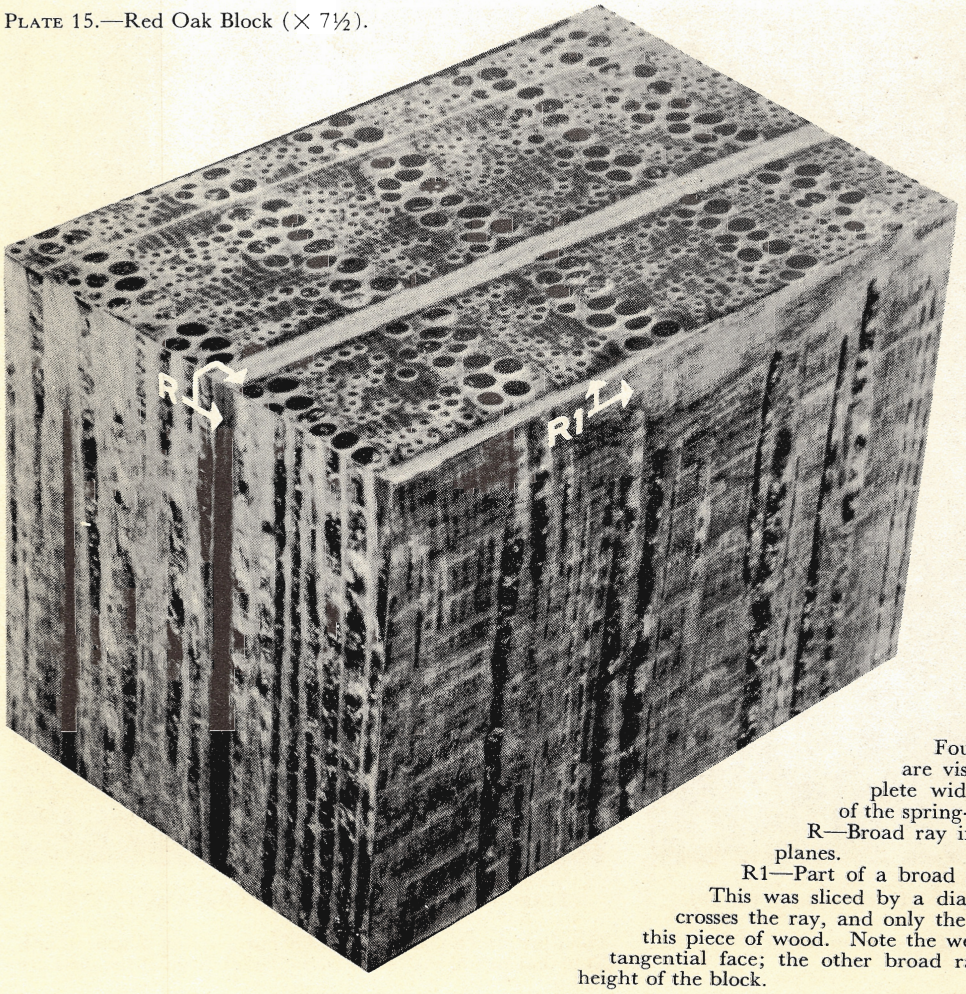
further elaborated into new layers of wood and bark. When, after a number of years, a wood layer has been separated from the outer living tissues by wood layers deposited subsequently, it usually undergoes slight chemical and physical changes and becomes heartwood, in which condition it ceases conducting sap. In many species, therefore, but not in all, the centre of mature trees and branches shows a definitely darkened heart. Young trees may, of course, consist entirely of sapwood. Unless sapwood has been darkened by stains, exposure, or processing, it remains light-coloured.

It is of interest to note that the heartwood of some species, such as the cedars and the white oaks, is very resistant to decay. Sapwood lumber, on the other hand, is not resistant to decay, but is sometimes preferred to heartwood because of its light colour, straight grain, and the absence of visible defects.

Softwoods

While certain structural characteristics of wood are perceptible to the naked eye, the observation of many of the more important requires the aid of a magnifier. If a small area on the end of a softwood log of a species such as red pine or Douglas fir is cut cleanly with a sharp knife, the annual layers may be examined closely. On such a clean-cut surface each annual layer may be seen to have a comparatively light and soft portion on the inside toward the pith and a darker and harder region at the outside toward the bark. Examined with a pocket magnifier (the so-called linen-tester of × 5 to × 10 capacity is cheap and serviceable for examining wood), each annual layer will, if cleanly cut, show a regular structure somewhat like a honeycomb (see Plates 16 and 17). Softwoods are composed largely of cells shaped like tiny tubes with closed and pointed

PLATE 15.—Red Oak Block (× 7½).



Four annual layers in this block are visible throughout their complete width. Note the large pores of the spring-wood.
R—Broad ray in transverse and tangential planes.
R1—Part of a broad ray visible in three planes. This was sliced by a diagonal cut which gradually crosses the ray, and only the lower part is contained in this piece of wood. Note the wedge-pointed ending on the tangential face; the other broad ray extends throughout the height of the block.

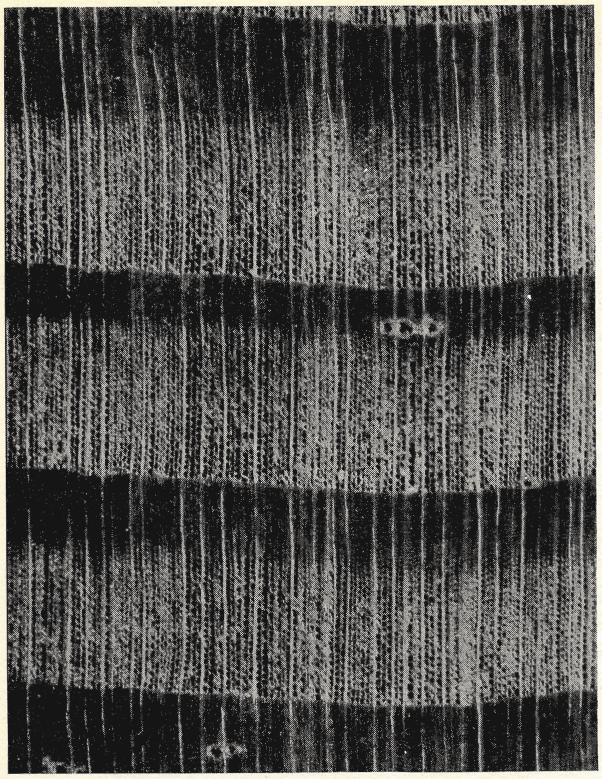


PLATE 16.—Douglas Fir (× 15).

ends. Packed closely together, as these long cells are, and arranged parallel to the log, a section cut across such tubular structures reveals their regular arrangement in radial rows, i.e., in series in a generally straight line from pith to bark. These tubular cells are popularly known as "fibres"[1], though this term is properly applied to a special type of cell with very small cavities found in hardwoods.

The variation in hardness between the inner and outer portions of the annual layer is due to clearly discernible differences in structure of the cells of the two regions. The inner region is composed of cells with relatively large cavities and thin walls, whereas the outer has cells with smaller cavities and thicker walls. The beginning of the growing period in the spring produces the light inner layer, known as spring-wood, and subsequent growth in the latter part of the growing season produces the outer part of the annual layer, called summer-wood[2]. The growing period ends with this hard layer of late wood, upon which the next year's growth adds a new layer of early wood, so that the contrast between light early wood and the darker and denser late wood distinguishes the separate annual increments sufficiently to give timber its characteristic layered appearance.

Examination with the magnifier discloses, in addition to the fibrous cells, numerous light fine lines which cross the annual layers in a radial[3] direction. Such fine lines are the wood rays, sometimes called the medullary rays. In softwoods, rays are minute, ribbon-like structures formed of short cells which are grouped into radially extending strands that pass at right angles to the fibrous elements of the wood. Rays are present in softwoods

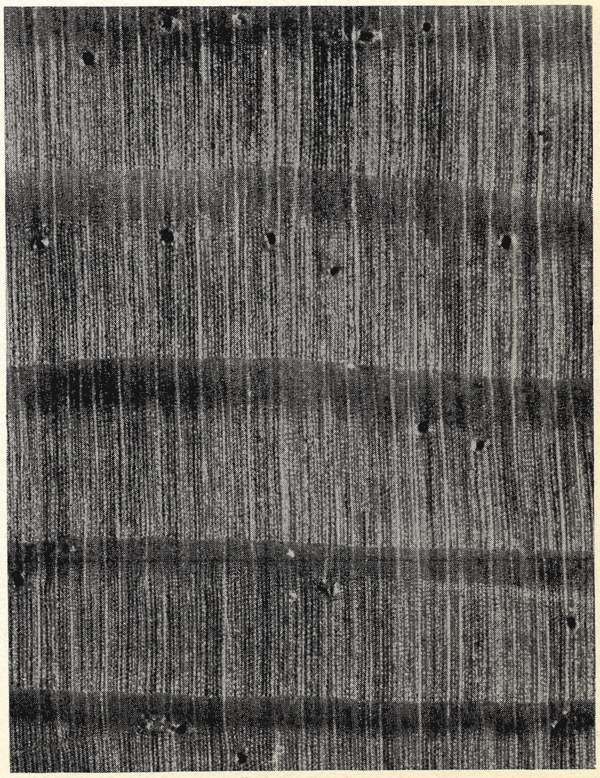


PLATE 17.—Red Pine (× 15).

[1] The tubular cells that compose the wood of softwoods are technically known as "tracheids". In the softwoods of Eastern Canada, the average length of tracheids is a little more than one-eighth of an inch. Some of the larger softwoods of Western Canada have tracheids twice as long. The tracheids are arranged with overlapping ends which communicate with neighbouring tracheids by means of pits through the walls, which permit the passage of sap along the cell cavities.

[2] The terms "early wood" for spring-wood, and "late wood" for summer-wood, are coming into increasing use.

[3] Radial, i.e., in a direction from the centre of growth to the outside of the log.

and hardwoods but, in identifying woods by their general appearance, are of chief diagnostic importance in the latter.

In some of the softwoods there are also resin ducts or canals which appear on the end surface (Plates 11, 12, 18, and 19), either as minute openings or as small, light-coloured spots. These ducts, which extend in the direction of the fibrous cells (the so-called vertical ducts), are often visible, especially in pine, on planed longitudinal surfaces, as fine streaks like longitudinal scratches. Resin ducts are sometimes open and empty in dry wood and sometimes closed, either because full of resin or because in heartwood the cavity generally becomes filled with a growth of small wood-cells known as tylosoids. Some resin canals extend radially, but these are often difficult to detect unless the ducts have become darkened.

Hardwoods

Hardwoods differ from softwoods in that the wood contains vessels which, on examination of the clean-cut end of a hardwood board, appear as great numbers of small round holes or pores in the wood. These pores are transverse sections of the vessels, cells of much larger diameter than the fibrous elements. The fibrous cells in hardwoods, which compose the greater portion of the wood, are shorter than the tracheids of softwoods, and are often so small in diameter that the cell cavities are indistinguishable when examined with a pocket magnifier. The vessel segments are comparatively short tubular cells with more or less open endings which fit together like minute lengths of pipe and form long continuous channels especially adapted for conducting sap. Owing to the porous appearance of wood exhibiting vessels when cut at right angles to the grain, the hardwoods are sometimes known as the porous woods. (See Plates 13, 14, and 20 to 27).

For purposes of identification, the hardwoods may be divided into two general classes on the basis of pore arrangement. One class contains pores which are not only very much larger in the early wood than in the late wood (see illustrations of oak, ash, etc., Plates 14, and 24 to 27), but are also close together in a more or less continuous layer in the early-wood region of the annual ring. Woods with such a distribution of pores are known as *ring-porous* woods. Other species with pores of more nearly uniform size distributed fairly uniformly throughout the annual layers are known as *diffuse-porous* woods. Ash and oak are examples of ring-porous woods, while birch, maple, and poplar are typical diffuse-porous species. In the diffuse-porous hardwoods, the annual layers are sometimes difficult to distinguish, as some of these woods do not show the distinct contrast in texture between early wood and late wood that is found in some of the softwoods. The structure of such hardwoods is often so uniform that a fine line is the only perceptible sign of the boundary of annual rings. Certain tropical woods, both hardwood and softwood, grow without very definitely distinguishable seasonal layers.

In the sapwood of both classes of hardwoods, the vessels are usually open, but, as the growing tree ages, the cavities of the heartwood vessels of many species become filled with ingrowths of small cells. These growths are known as tyloses. In some woods, the cavities become filled with deposits of gummy substances. The effect of tyloses may be illustrated by reference to the fact that one can blow through long sticks of oak sapwood or even through heartwood of the red oaks, where the vessels are mostly unobstructed, while heartwood of the white oaks, its vessels

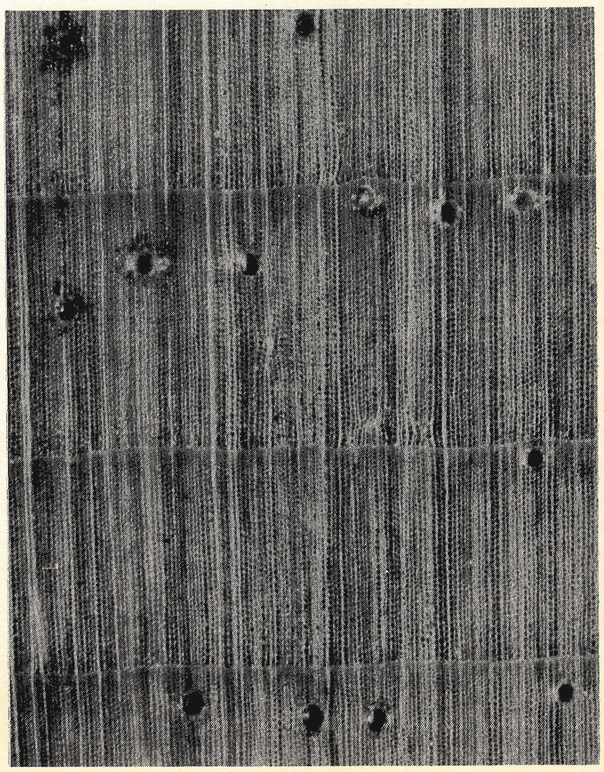


PLATE 18.—White Pine (× 15).

closed with tyloses, is relatively impermeable except at very high pressures. Tyloses are visible, in the large vessels of the white oaks and certain other hardwoods, as shining structures frequently resembling tiny soap-bubbles (see Plates 24 and 27).

The rays in hardwoods are much more strongly developed than in softwoods. Although in some hardwoods, as in softwoods, rays are invisible without the aid of a lens, in others the rays are of greater widths, sometimes reaching a thirtieth of an inch in oak (Plates 15 and 26), and are several inches in height (the height is measured in the direction of the fibres, which is commonly called the direction of the grain). The rays, which function as reservoirs of food material for the growth of the tree, are composed of cells, called "parenchyma", which are much shorter than the fibres.

When woods with wide rays are quarter-sawn, the rays lie on the wide faces of the board and expose their band-like character in attractive streaks across the grain (see Plate 28). The rays in such boards often have a wavy or curved outline, owing to the fact that in commercial practice the board may not have a truly radial face, and also because the large rays are rarely quite straight. On tangential surfaces of boards, the rays are usually least conspicuous, because of their small area in cross-section. In certain woods, however, rays of approximately equal size may be "storied" (spaced approximately equidistant in more or less uniform rows), and such arrangement of the rays, which are not conspicuous individually, causes the tangential surface of wood to appear covered with "ripple marks"—fine, variable lines across the grain, which in some species may run upwards of one hundred to the inch.

Another character of value in identification in some species is the visible presence of wood parenchyma. When present, wood parenchyma often appears in whitish patches, lines, or even as fine dots (see Plates 23, 24, and 26). When light-coloured, it may be invisible or difficult to distinguish in the light-coloured hardwoods, but sometimes it may be of diagnostic importance in wood identification. Such tissue may occur at the end of annual rings, scattered diffusely, grouped about the pores in well-defined bands, or in various combinations and gradations of development.

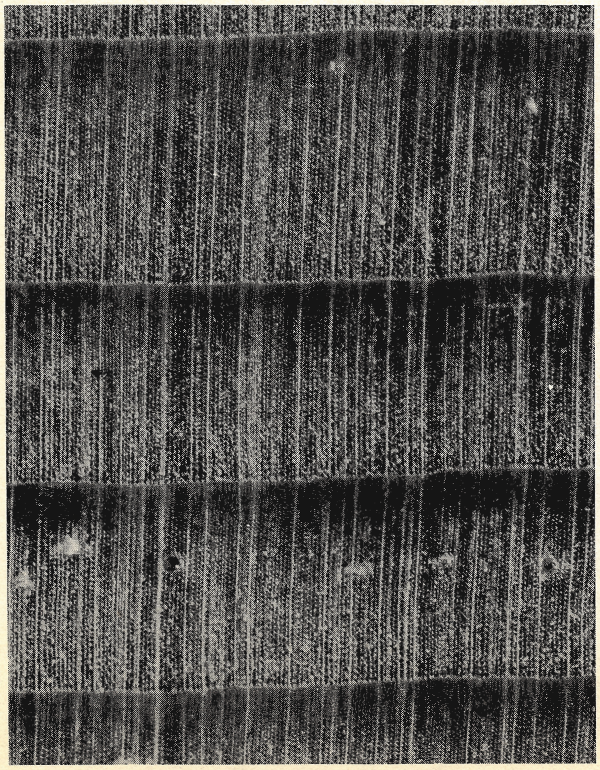


Plate 19.—Engelmann Spruce (× 15).

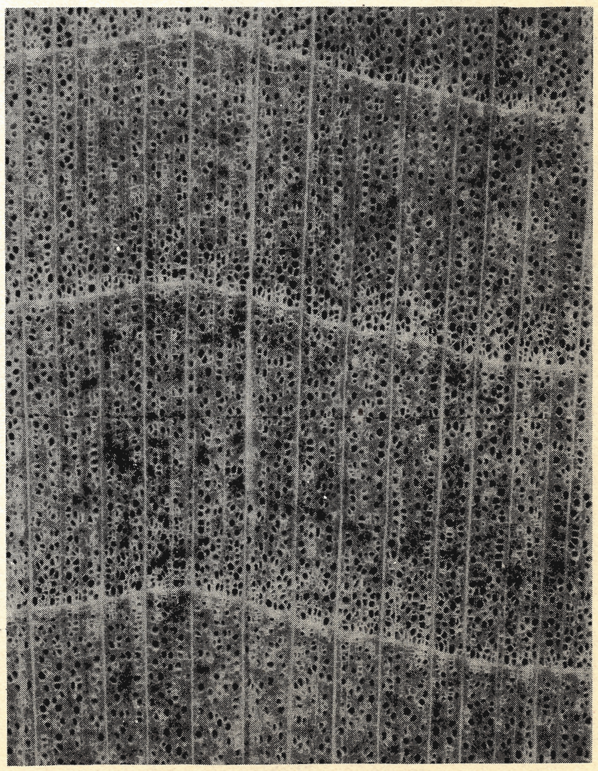


Plate 20.—Basswood (× 15).

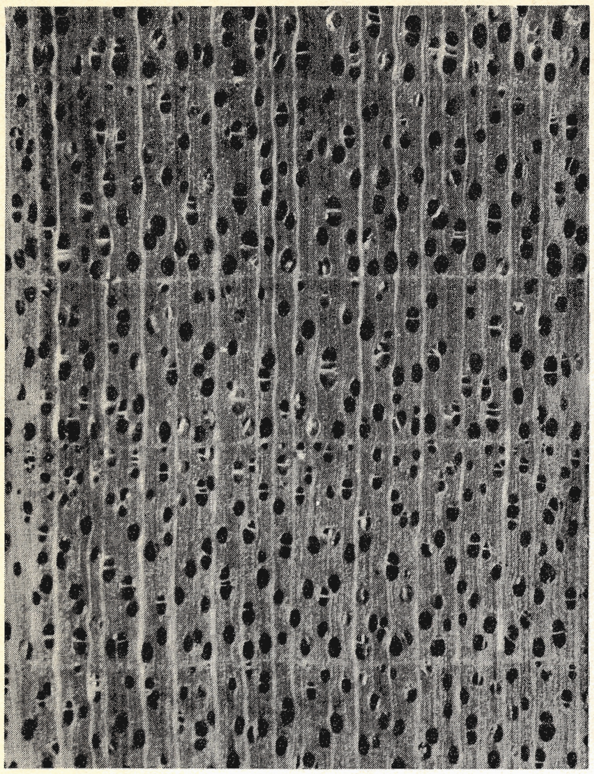


PLATE 21.—Yellow Birch (× 15).

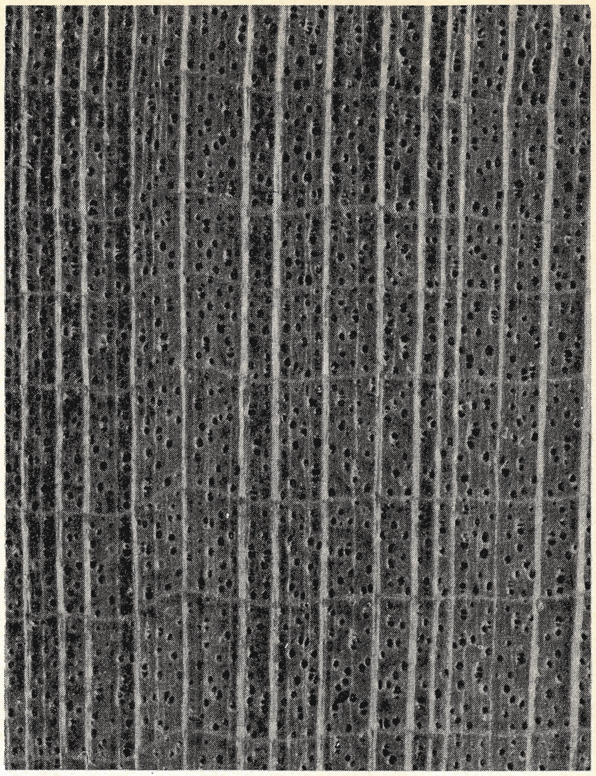


PLATE 22.—Sugar Maple (×15).

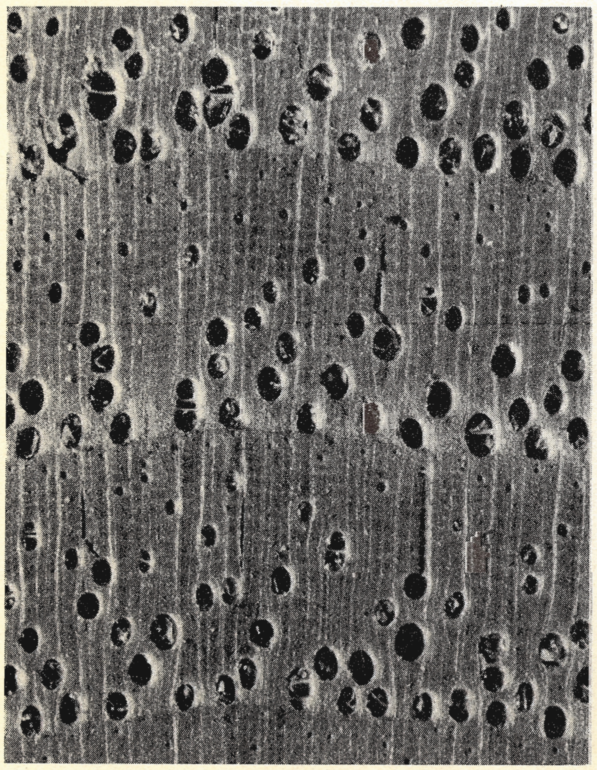


PLATE 23.—Hickory (× 15).

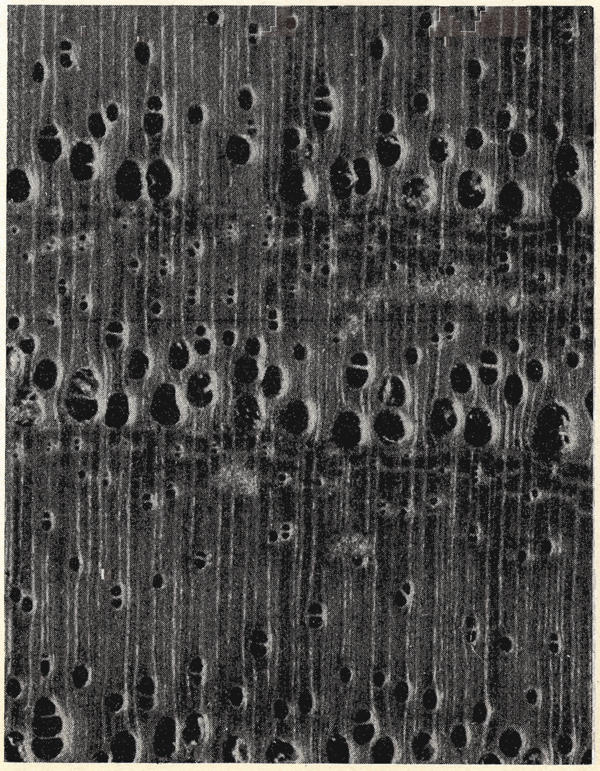


PLATE 24.—White Ash (× 15).

PLATE 25.—Ash with Narrow Growth-rings (× 15).

Careful observation of the various structural characters of wood so far enumerated may be sufficient to identify the different common timbers. Other properties of wood, such as its weight, colour, odour, taste, and even its size, may be decidedly important in such identification, but as all of these properties (except the structural characteristics) may become considerably altered, either because of aging or as a result of various treatments, it is plain that observation of the structural features of wood presents the surest diagnostic method. While many experienced woodworkers have learned by long practice to distinguish the woods they use on the basis of general appearance, such methods are sometimes difficult to describe satisfactorily, and the beginner will probably do well to commence by observing the fundamental structure of common woods, even though his object is to devise methods of rapid identification by general appearances. With a preliminary grounding on structural characteristics, close observation of wood will soon demonstrate the simple relationship between the structure and the general appearance of the different kinds of timber.

SOME ABNORMAL CHARACTERISTICS OF WOOD

Wound Resin Ducts

THE occurrence of abnormal characteristics will, by anyone who has had a little experience in examining wood, be readily recognized as belonging outside the category of typical occurrences. Mechanical wounding of the growing tissue of some species may cause the formation of certain structural characteristics which are absent in normal wood (22), for example, the traumatic or "wound" resin ducts in hemlock (Tsuga) and true fir (Abies). In these species, wounding may cause vertical resin ducts to be present in the wood and, especially in balsam fir, so close together that on transverse sections of wood the neighbouring ducts form short lines that follow the curvature of the annual ring. Examination of the specimen elsewhere than in the abnormal area will show that such structures are absent in normal wood.

Burls

In common North American usage a burl is "a swirl or twist in the grain which usually occurs near a knot but does not contain a knot", according to the current (1950) rules of the National Hardwood Lumber Association, which state that such burls "not containing unsound centers are admitted in the cuttings except when otherwise specified". In this sense, therefore, a burl may be a blemish or even a defect.

In another important meaning, the term "burl" signifies wood with a desirable ornamental figure. Such ornamental burls typically contain wood with interlocked or undulating grain and may also be more or less thickly spotted with structures resembling bird's-eye or small knots. According to English practice the term "burr" appears synonymous with this meaning of burl.

Ornamental burls may, therefore, be parts of the tree particularly likely to show ornamental figure, such as the butt ends which contain wood with swirled or twisted figure owing to the proximity to large knots and other structural irregularities, or they may be eccentric growths (see "galls") induced in trees by the action of foreign organisms on the growing tissue so as to cause swellings by local acceleration and distortion of growth.

Utilization of ornamental burls, usually by slicing in thin veneers and applying the figured wood for decorative uses, is a specialized field of industry.

Foreign Matter in Wood

The growth of the tree may cause foreign materials to be completely enclosed by wood, with considerable distortion of the surrounding wood structure. For example, a tight metal band about a tree trunk may, by constricting the conductive passages of the inner bark, cause local congestion of the descending food material, with the result that the trunk becomes swollen by the growth of wood just above the constricting band, which may become entirely enclosed by layers of wood that in the course of time literally "flow" over the obstruction. Such foreign objects as chains, scythes, and horseshoes, hung over branches and forgotten, are sometimes found embedded in, and so deeply overgrown by, wood as to be near the centre of large branches, while the occurrence of nails and spikes far in the interior of butt logs is a common source of difficulty to sawyers.

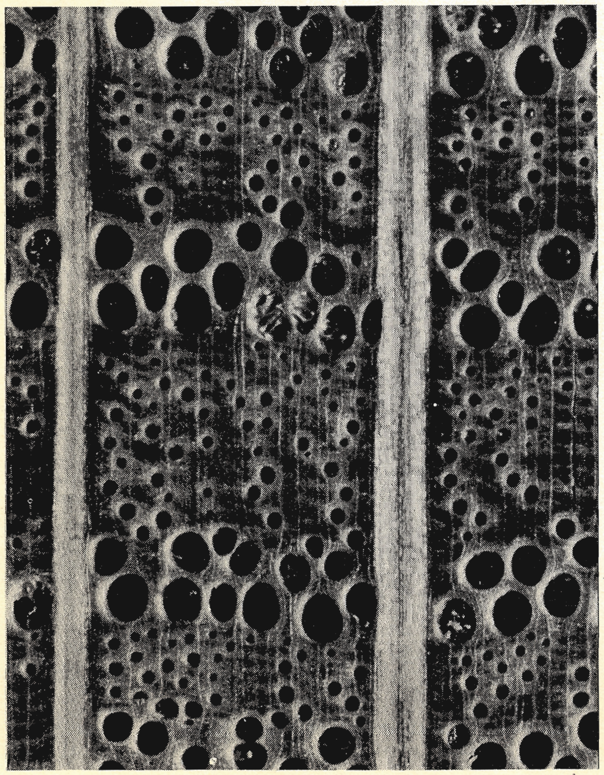


PLATE 26.—Red Oak (× 15).

Abnormalities Due to the Action of Parasites

Investigation of the exact processes of growth that take place in the cambium seems necessary to obtain information on the mechanism of the production of some abnormalities in wood. Parasites, both plant and animal, produce certain modifications of wood structure, known as galls, by stimulating the cambium to accelerated and specialised growth locally. While various forms of gall are known, the mechanism of their production is not completely understood. The presence of Sanio's trabeculae[4] in association with bird's-eye, abnormally enlarged resin ducts, and various structural abnormalities that have not otherwise been accounted for, indicates the presence of filamentous fungous parasites in the cambium of growing trees as the primary cause of these peculiarities.

Pith Flecks

In hardwoods, small "pith flecks" are sometimes found. These flecks are usually visible as small definite brown lines or streaks in the direction of the

[4] Sanio's trabeculae are small rod-like structures which extend like minute beams across cell cavities and occur frequently in both hardwoods and softwoods, although most often reported in the latter. Trabeculae are visible only in microscopic preparations with great magnification. These microscopic "rods" occur typically in continuous radial series extending through the cell cavities from one tangential wall to the other, like an extremely thin nail driven straight into the tree from the bark. The typical form is a hollow rod of round cross-section, although various degrees of distorted shape occur. A series may extend through several annual layers. The rods seem to be the result of the deposition of cell-wall material about a fungous filament in the cambium, with the result that the structure is perpetuated in the series of cells developed from the cambial cell. Such an origin explains the perpetuation of long series of the trabeculae extending across several annual layers of both wood and bark. Apparently the composition of the trabeculae is similar to that of the walls of the cells of which they are a part.

Additional evidence confirming this theory of the origin of Sanio's trabeculae has been encountered consistently in examining wood material, since its announcement at the Boston meeting of the American Association for the Advancement of Science in 1922 (15). The presence of trabeculae in considerable numbers, therefore, seems valid evidence for suspecting the agency of cambial fungi in causing the abnormalities consistently associated with the trabeculae, particularly when other anatomical evidence favours such a view.

The trabeculae seem definitely associated with certain structural abnormalities for which a causative fungus is thereby implied. Some notable peculiarities which, as indicated by the presence of trabeculae, are due to fungus parasites in the cambium, are various types of bird's-eye structure, and the occurrence of abnormally large horizontal resin ducts in conifers. Trabeculae also are likely to be present in regions where the cambium has been exposed to infection, and occur particularly in wood formed after wounds and in close proximity to fungus cankers.

grain, and are seldom sufficiently numerous to constitute an important blemish. They are usually visible for an inch or more on planed surfaces and have been named pith flecks because of their superficial resemblance to the brownish pith. Such streaks are caused by mechanical damage to the cambial tissue by the larvae of small species of beetles which bore tunnels in the cambium (5, 33). The tunnelled wood is replaced by irregular brownish cells, after which the repaired cambium forms normal wood, resuming its activity and producing the wood elements in the same sequence that obtained before the insect attack, so that the principal rays usually have identical spacing in the wood inside and outside the fleck.

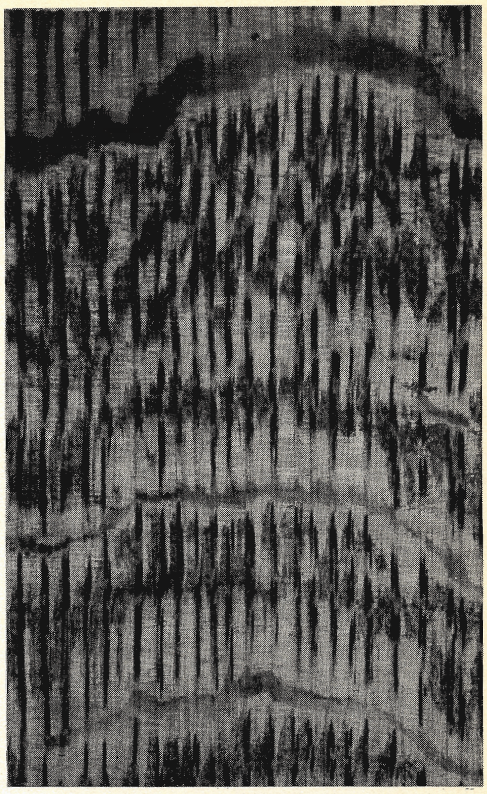


PLATE 28. Quarter-sawn Oak—Natural size.

Pitch Pockets

Small pitch pockets in certain softwoods may have an appearance somewhat like the flecks in hardwoods. Typical pitch pockets are small cavities of flattened, lenticular, cross-section that lie in a tangential plane or conform to the annual rings. Such pockets may be less than an inch wide and only a few hundredths of an inch thick, or occasional-

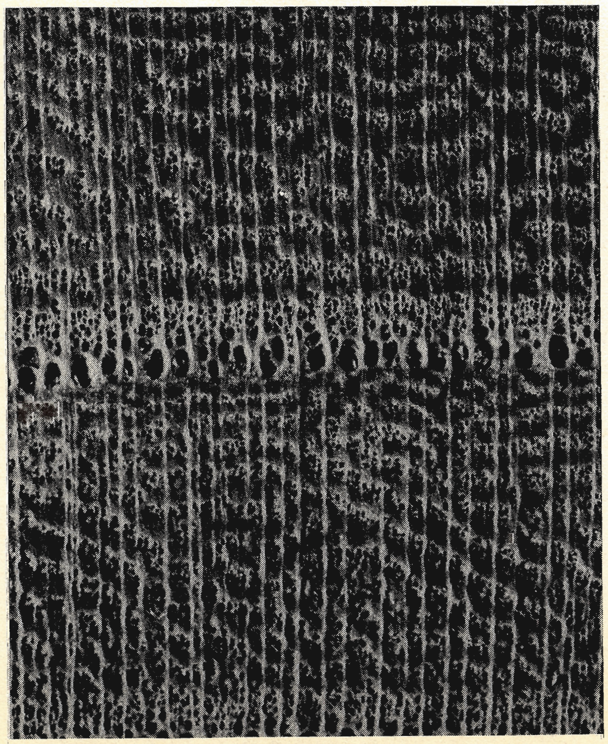


PLATE 27.—White Elm (× 15).

PLATE 29 Flat-sawn Oak —Natural size.

ly, in large trees, may occupy a space of several cubic feet. Pitch pockets typically contain oleoresin and occur in wood of species characterized by resin ducts.

Abnormal Colour

The occurrence of abnormal colorations in wood is usually related to the presence of fungal organisms that produce stains and cause the disintegration of timber known as decay or rot. It is, of course, possible for stains to be caused by contact with dyes or with materials that produce more or less rapid colour changes by acting on the wood substance or on the cell contents, and the term "chemical stain" is sometimes employed to describe various types of such coloration not obviously caused by fungi. There is also the normal change in colour of wood surfaces that darken or change with prolonged exposure.

A so-called "mineral stain" or "mineral streak" is occasionally reported in maple. It sometimes appears in isolated patches of olive-green colour an inch or two in extent along the grain. The wood in the dark areas appears harder than normal wood, and, where the streaks are numerous, may tend to dull cutting tools. In certain instances, the greenish coloration is associated with the presence of fungi, and in this condition the stain may cover wider areas in the wood. Since fungi are often found in such stained regions of the wood, it is possible that the stain is due to this cause. When the stain is evident over wide areas, it is noticeable that the wood shrinks more in drying than does normal wood and, in thick stock, is liable to considerable de-grade owing to the formation of internal cracks.

It is stated by Hubert (20), who also gives evidence that the "streak" is an early stage of common heart-rot in maple, that the "mineral stain" or "streak" noted in wood from certain regions is sometimes supposed to be caused by the absorption of iron or copper salts from the soil, and that the dulling effect of such wood on tools "lends colour to the belief that an infiltration of 'mineral' is responsible for the defect".

Discoloured streaks denoting the incipient stage of decay in wood often undergo abnormally high shrinkage, resulting in formation of local checks during seasoning.

Mineral Content

The mineral content of wood, judged by the matter remaining as the incombustible ash when wood is burned, is very low in most of the common species, although very many woods are normally characterized by the presence in specialized cells of minute crystals which are more or less conspicuous when viewed at high magnification. Calcium oxalate is a common material secreted by plant cells in crystals of various forms, and calcium carbonate and other lime salts are of frequent occurrence. Certain woods, such as the well-known heavy and dark-coloured grades of mahogany (*Swietenia* sp.), are characterized by white amorphous deposits in the vessels. In some tropical species, "stone" concretions of fairly large size are found, and a study which reports concretions as large as half a cubic foot suggests the formation of such substances (chiefly calcium carbonate) may be due to deposition from the sap in "bleeding" from wounds (19). The occurrence of minute silica bodies is not rare in plants, and it has been considered that the presence of silicic acid in certain tropical woods may be of some effect in rendering the timber of certain species resistant to the attack of such marine borers as Teredo (4, 12).

Grain and Texture of Wood

Mention is made hereunder of some common terms that are used in connection with wood.

Grain is a term used very frequently in descriptions of timber. While this word is familiar, its current popular use has so many different meanings as to be confusing, if not contradictory, and any discussion of lumber must therefore define these.

Grain is sometimes used to signify the size of the constituent particles of wood; thus, some of the hardwoods which contain cells of sufficiently large diameter to be conspicuous are called coarse-grained or (particularly by painters and finishers) open-grained, whereas woods composed of narrow cells are described as fine-grained or close-grained[5]. Again, some woodworkers call the annual layers grains, wood with wide and conspicuous annual layers being called coarse-grained, and wood with narrow layers, fine-grained. The natural pattern or figure of wood, too, is sometimes described as the grain, though this practice may not convey a very precise meaning.

[5]For fuller consideration of the various meanings of "grain" see *The Properties and Uses of Wood*, by A. Koehler, McGraw-Hill Publishing Co., N.Y. pp. 20-28, 1924.

There is one definition of grain, however, that is in general use, and this is the direction of fibres determining a plane of cleavage. It is commonly agreed that a straight-grained piece of timber is one that splits parallel to the axis of the piece. The definition of slant grain and spiral grain is obvious, since trees sometimes show a pronounced spiral growth, with the fibrous cells inclined at an angle from the axis of the trunk so that splits which follow the direction of the fibres extend around the log in a spiral. Sometimes the direction of fibres in neighbouring annual layers is inclined to the left and right respectively so that wood with such interlocking grain is difficult to split. Inasmuch as uses of the term grain otherwise than in reference to the direction of the fibres are susceptible of other simple definitions, it is logical generally to consider that grain should be understood to signify the direction of the fibres, unless a different meaning can be accurately conveyed. A description of wood as having wide or narrow growth-rings conveys a more accurate picture of the wood than some reference to the grain, which is susceptible of so many different interpretations.

The common use of the term "texture" in describing the prevailing size of the cell cavities of wood seems to replace with benefit a frequently implied meaning of grain. Texture is commonly accepted as signifying the size of the constituent parts, and, as the cells are recognized as the constituent units of wood, texture has a legitimate and definite meaning here which grain, because of its other meanings, may lack.

The figure of wood may be due to a variety of causes unrelated to any of these definitions of grain. In some instances, however, the figure is caused by the arrangement of the fibres. Wood with wavy grain is composed of cells which follow the direction of wave-like undulations. When the undulations of the grain are comparatively short, the figure may be called "curly grain". These common descriptions are based on the interpretation of grain as the direction of the fibres.

The terms "edge-grain" and "flat-grain" have such wide use as to be necessary in any wood-user's vocabulary. An edge-grain or vertical-grain board is one with faces which occupied a nearly radial position in the log, i.e., approximately in the plane passing from the central pith to the periphery of the log. The faces of such boards are approximately parallel to the rays, which in some woods (especially the oaks) show a characteristic figure, sometimes called "silver grain" or "flake", when thus exposed (Plate 28). Boards with faces approximately at right angles to the rays are called flat-grained. Such use of the term grain seems to arise partly from the conception of grain as synonymous with annual layer. In faces of truly vertical-grain boards, the annual layers are visible only along their edges (Plates 28, 30), while a truly flat-sawn board presents to view a relatively broad expanse of each layer (Plates 29, 31). Such flat-sawn boards, with faces that occupied a plane tangential to the growth-rings, may be cut from large trees so as to contain annual layers with very little curvature. In consequence, such boards show annual layers that appear nearly flat and parallel with the faces of the boards. End-grain refers to the section visible on ends of logs or smaller pieces of wood at right angles to the fibre direction.

SOME STRUCTURAL VARIATIONS IN WOOD

THE properties of wood may vary even in the same species, and such variations must be considered in so far as the appearance and the utility of the wood are affected. Variations in the rate of growth are often of great importance in affecting the appearance and properties of wood.

Variations in Softwoods

In the heavier softwoods, which normally contain a large proportion of summer-wood, a moderate rate of growth usually tends to produce the heaviest wood; extremely wide rings or extremely narrow ones tend to produce a smaller proportion of summer-wood than does a medium rate of growth in timber from the usual commercial stands. Woods such as spruce, with relatively little summer-wood in the annual rings, are generally found to be heaviest when of slow growth. This is due to the fact that each additional ring per inch adds its small increment of summer-wood. In general, therefore, the narrower the annual layers, the heavier the wood, within the limits of growth-rate usual for commercial spruce timber. The heavy softwoods like Douglas fir and the hard pines, on the other hand, frequently have 40 per cent of summer-wood in each annual layer, but the proportion of summer-wood occurring in such species becomes somewhat reduced from the

PLATE 30.
Quarter-sawn
Softwood with
Conspicuous
Summer-wood
—Natural size.

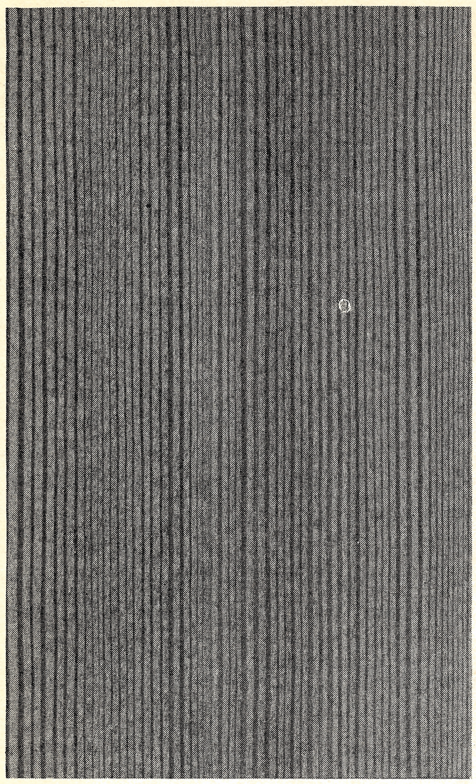


PLATE 31.
Flat-sawn
Softwood with
Conspicuous
Summer-wood
—Natural size.

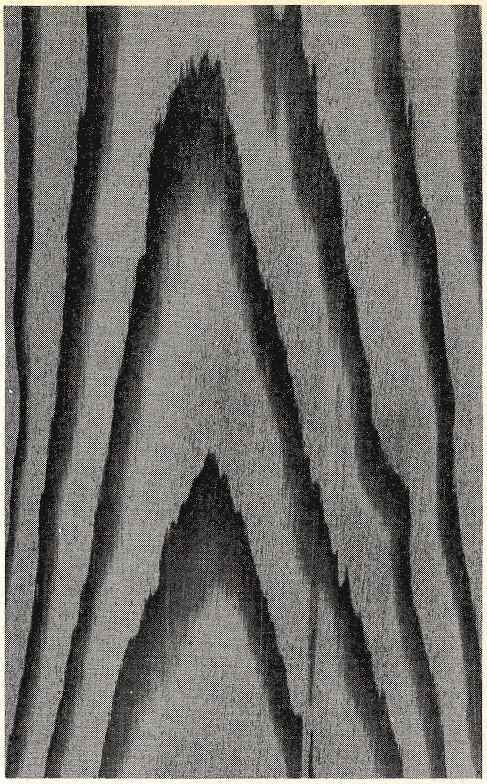


PLATE 32.—Compression-wood in Spruce.

maximum by extremes of rapid or slow growth, causing the density and strength factors to vary accordingly (Fig. 1).

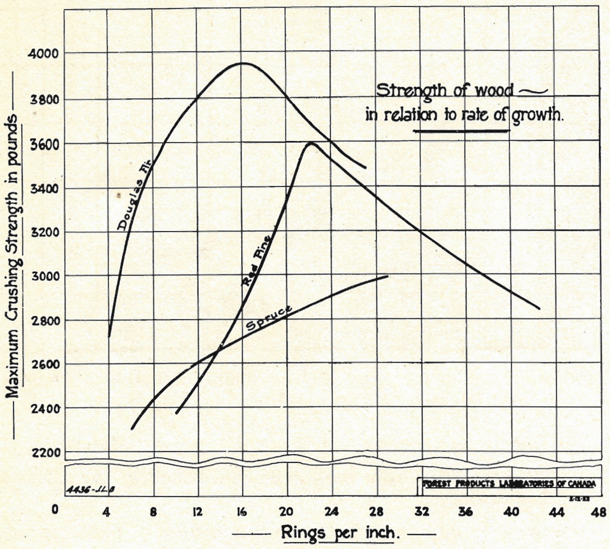


FIGURE 1.—Curves Showing Trends of Variability in Strength of Three Shipments of Wood.

Mature trees of large size often furnish wood of varying rates of growth, exhibiting corresponding variations in technical properties. Wood from the central portions of logs from such trees often has wide growth-rings which become narrower toward the outside of the tree. In large old trees of Douglas fir, for example, the wood of moderate growth-rate is characterized by a large proportion of summer-wood, and is therefore heavy and strong. Such material is most desirable for heavy structural timbers. The wood at the outside is often of very slow

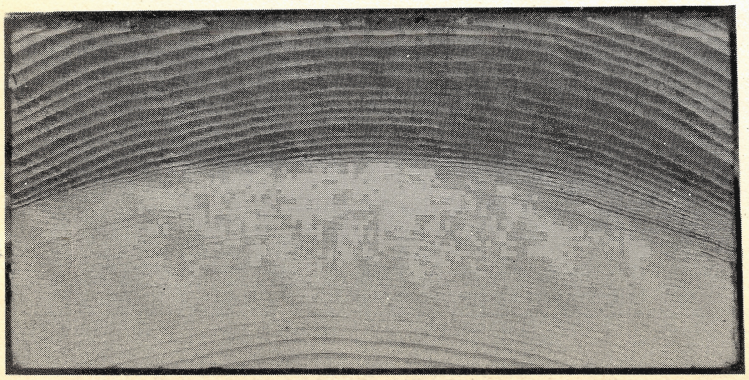


PLATE 33.—Compression-wood on End of Spruce Scantling.

growth, with a consequently smaller proportion of summer-wood. Such wood is relatively uniform in texture, since it lacks the extreme contrast found in alternating bands of dense summer-wood and light spring-wood common to material of moderate growth-rate. It cuts easily and has the uniform working qualities especially desirable for joinery. This type is sometimes known as the soft yellow Douglas fir, and by those who are not familiar with fir, it is sometimes mistaken for a species different from the denser fir of moderate growth-rate.

The faculty of producing different types of wood in different regions of the tree is not confined to any particular species. Similar tendencies are noted in some of the pines, which produce a fine grade of soft-textured wood in the outer layers of large trees. Such variation may be seen in cross-sections of mature trees. Wood near the pith is likely to be of higher density than wood of similar rate of growth (i.e., with the same number of rings per inch) from the outer part nearer the bark. Wood of a certain rate of growth from a young tree may be denser than wood of the same rate of growth from a tree 50 years older. This tendency to variation in density may be noted even in the wood of a single tree that is very old. A series of trees of white spruce tested at the Laboratories showed an average age of 135 years at two feet above the ground. The wood formed during approximately the first 90 years, comprising half the volume of the wood at this point, was found to be of the same density as the outer half, which was, of course, formed after the tree was 90 years old. Although the density was the same, the average rate of growth of the outer half was 23 rings per inch, and that of the inner half, formed in the earlier stages of growth, only 13 or 14 rings per inch. In this particular stand of spruce, it was found that the density of the wood increased consistently toward the top of the tree as the upper levels became progressively younger (17).

The fact that the wood produced by cambium of young regions of such trees was generally found to be heavier than wood of comparable growth-rate produced by that of old regions is due, no doubt, to complex causes, among them, possibly, the fact that what may be called the young regions of the cambium are nearer to the source of food material than are the older regions. The food which is transported in solution from the leafy crown down the trunk nourishes first the upper regions. It is, there-

fore, possible that the food-stream becomes somewhat depleted by demands of the nearest growing tissue, with the result that, before it reaches the low levels of the tree, changes in the quality or quantity of the food used for growth cause the variation noted in the density of wood produced at different levels.

Many good pulpwood stands of Eastern Canada are composed mainly of trees that are too small to yield many logs large enough for saw-timber. Spruce from such stands is generally of higher basic density than spruce of sawlog size. The fact that wood of small spruce is basically heavier than that of large trees may generally be explained by the fact that the trees are small because of their slow growth, which causes spruce to have wood of relatively high density. In many species, the basic density at the butt of the tree is greater than that of wood from upper levels.

Figure 2 indicates the relation between diameter of log and density[6] of spruce wood. As the pulpwood bolts of eastern species are generally less than 10 inches in diameter, it is evident that weight of dry material per cubic foot is somewhat greater in the spruce used for pulpwood than in the larger logs used for lumber. The weight of chemical pulp that is obtainable from a given weight of pulpwood is reasonably constant, so a given volume of dense wood will produce a greater amount of pulp than a similar volume of less dense wood (23). Thus small logs, which have heavier wood than the general run of material suitable for saw-timber, may have some advantage over large logs for use as pulpwood.

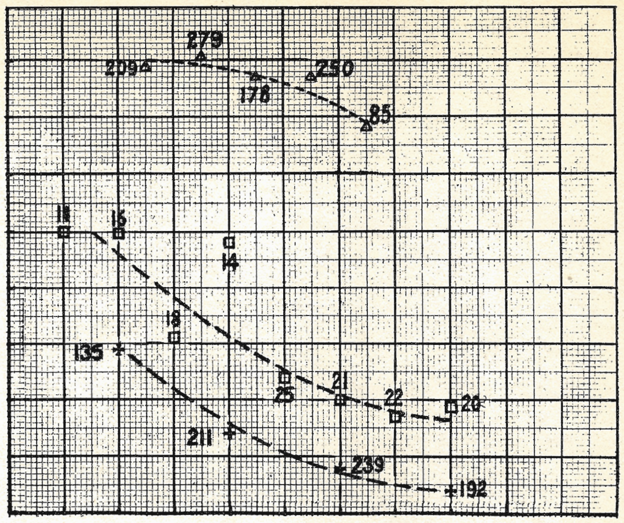


FIGURE 2.—Curves Showing the Relation between Density and Diameter of Spruce Logs of Three Species.

□ = Engelmann spruce, tested at the Ottawa Laboratory.

+ = White spruce from Saskatchewan, tested at the Ottawa Laboratory.

△ = Spruce pulpwood from Abitibi district: black spruce and white spruce mixed.*

*Figures for this pulpwood are from a report of the Wood Measurement Committee of the Canadian Pulp and Paper Association (see Pulp and Paper Mag. of Canada, International No., Feb., 1928). Wood of black spruce has higher density than other spruces tested at the Laboratories and is responsible for the comparatively high density of this mixed pulpwood.

[6]Note on "density", "specific gravity" and "weight" of wood. The density is here based on the green volume and on the oven-dry weight of the samples tested, and indicates the weight of dry wood per unit volume (grams per cubic centimetre) of green material. To convert these figures to pounds per cubic foot, multiply by 62.4.

The density of any substance ordinarily signifies its weight per unit volume under stated conditions.

The specific gravity of a substance is the ratio of its density to that of water. When density is expressed in grams per cubic centimetre, the figure for density represents the specific gravity as well.

The water in freshly-felled wood may account for the greater part of the weight, or in seasoned wood the moisture content may be less than 10 per cent, so that it is evident that the weight of a given volume of timber is likely to vary greatly according to its moisture content. The extent to which the wood shrinks in drying also has its effect on the density. It is therefore the common practice to determine the weight per unit volume of dry wood substance in fully saturated green material as a useful basis for comparing the density of woods. This standard of comparison, the weight of oven-dry substance per unit volume of saturated wood, is commonly known as the "basic density".

The weight of dry material per unit volume of green wood, of course, does not represent the actual weight per unit volume of timber under conditions of actual use. The weight per unit volume of timber should always be accompanied by a statement of the moisture content of the wood at the time that weight was determined.

It is common practice to compare different woods and to describe them as "light", "moderately light", "heavy", etc., according to their weight per unit volume in air-dry condition. In North American practice, woods are so compared at a moisture content of 12 per cent, but an internationally accepted standard establishes 15 per cent as "air-dry" for purposes of comparison.

In testing timber, it is common practice to determine also the weight per unit volume of wood when in the oven-dry condition. This value has certain uses in calculations, although, of course, timber in the oven-dry condition is never encountered in actual use.

The so-called density or specific gravity of wood may therefore be based on the green volume and oven-dry weight, which shows the weight of dry material per unit volume of wood at saturation. It may be based on both the weight and volume when oven-dry, or on the volume when tested (at some moisture content between the saturation point and oven-dryness) and on the oven-dry weight. It is obvious that in stating figures for the density or specific gravity of wood, it is essential to mention the basis of measurement.

Aside from the fact that relatively large logs are preferable in that material may be more economically sawn from them, large logs furnish relatively large proportions of lumber free from knots. Knots are the ends of limbs which generally originate from the pith of the tree. While the branches are living, the fibres of the knot connect with the fibres of the tree, but in forest stands the lower limbs lose their function and die because of the dense shade. With cessation of growth by the branches, the wood of the main trunk ceases to maintain its organic connection with the dead branches and commences to grow over them, just as it would over foreign matter embedded in the wood. When the branches finally drop off, the annual layers gradually cover the portion embedded in the trunk, so that in time no traces remain on the surface of the log. Thus, if the log is large it may have formed a thick layer of clear wood outside of the old knots. Trees that grow in the open, where sunlight is not restricted, are likely to have persistent branches, however, and, therefore, to produce knotty timber.

It is for this reason that large, forest-grown trees are in particular demand, since the highest grades of lumber and veneers (aside from purely ornamental material) are produced from the clear outer wood found in the lower region of the trunks of such trees. This, of course, applies to hardwoods as well as to softwoods, although certain "specialty" stock not required in large sizes may sometimes be selected from relatively small trees. White oak staves for tight cooperage, and ash and hickory for handles and sporting goods, are examples of such specialty stock prized for straight grain, strength, and uniformity. Even in wood of white pine, which has a uniform structure and is therefore susceptible to relatively small variation, the clear, soft material from the outer region of large logs from old trees is especially prized for its uniform carving qualities and general ease of working with tools, as well as for its freedom from defects.

The softwoods showing the greatest normal variation in density are the type with considerable contrast in texture of spring-wood and summer-wood. Those with small or moderate amounts of summer-wood, into which the spring-wood merges gradually without abrupt transition, generally show increases in density with diminishing width of the growth-rings (13), except when this relationship is modified by maturity of the trees. Softwoods of uniform texture with the minimum of summer-wood (as typified by white pine) appear least affected by variations of growth-rate (16).

Indication of the degree of variation encountered in any property of wood (or of other material) is usually recorded by arranging the results of measurements or tests of the particular property in some order of magnitude, so that the relative proportion of the test samples in each class may be easily recognized. Since variations in the specific gravity or density of wood are due to structural variations and exert a proportional influence on other physical or mechanical properties, it will be useful to illustrate the variation in specific gravity encountered in testing reasonably large amounts of wood. In Figure 3 are presented graphic illustrations of the varying specific gravity of wood of white spruce from four different localities, wood of each locality being represented by tests of 400 to 500 logs from 100 trees. Each individual test represents the specific gravity of a complete cross-section of a log. The values for specific gravity are arranged in classes from left to right, beginning with the lightest. This arrangement is sometimes known as a frequency distribution chart or polygon, because it shows the relative frequency of occurrence of each class. The middle classes contain the largest number of tests, while the classes farthest to the left and right, which represent, respectively, the lightest and the heaviest wood, contain comparatively few. The dotted lines joining the total tests in each class are fair approximations of the so-called curve of probability or normal variation, in which the number of individuals of each class is supposed to increase symmetrically from the extremes of variation as the mean is approached. These figures show that the random selection of a spruce log would not necessarily result in the choice of one with the average specific gravity. However, since the figures show by the heights of the various vertical lines just how much wood of each class contributes toward the average of the whole group, the degree of variation is illustrated sufficiently to show that half the material is within about 5 or 6 per cent of the average, and that, therefore, in random selection of a log the probability that its specific gravity will be within about 5 or 6 per cent of the mean is 50%. Therefore, this material is said to have a probable variation of 5 to 6 per cent. The curve also shows that, in such random selection, the chances of selecting an extremely light or an extremely heavy sample

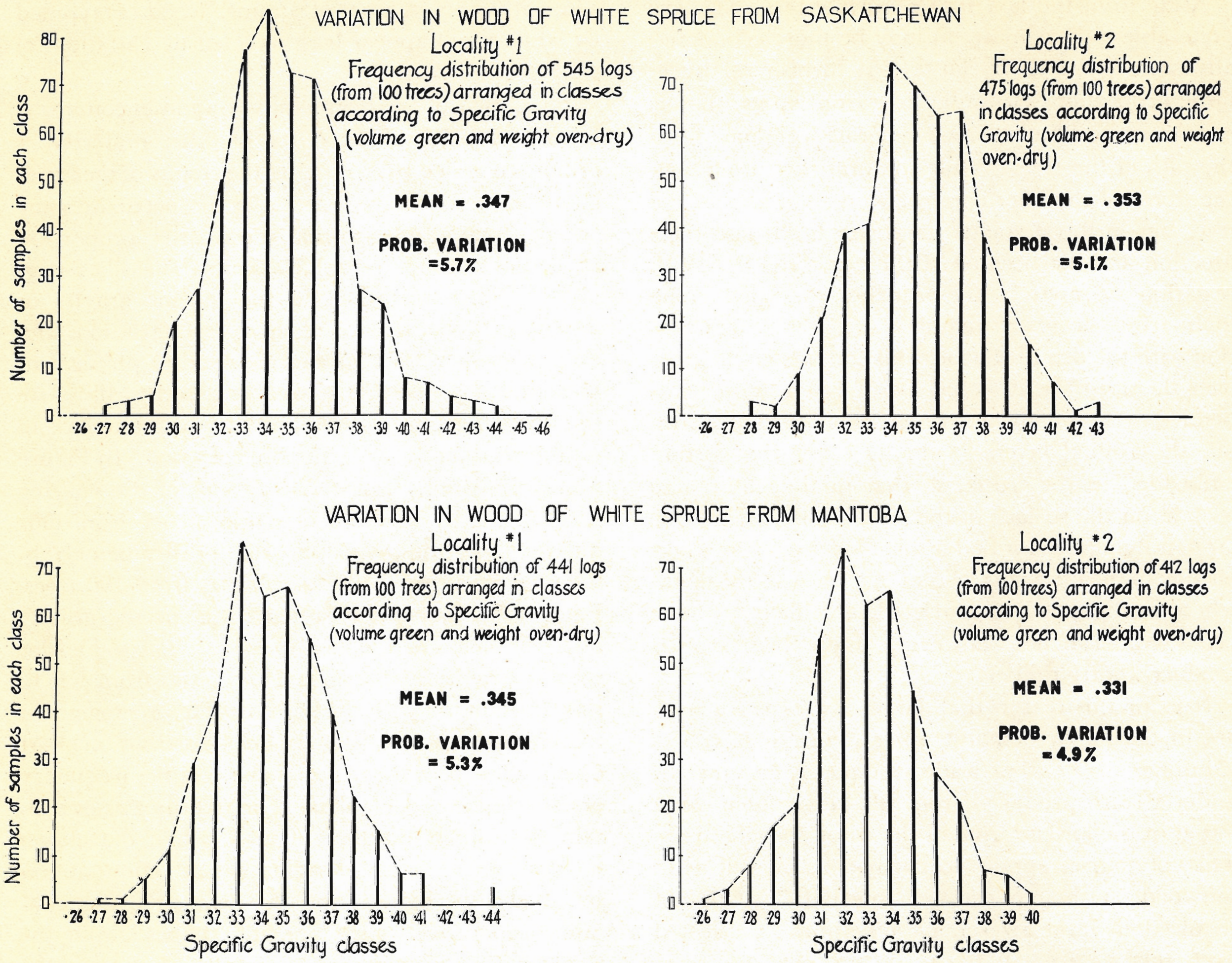


FIGURE 3.—Diagram Illustrating the Variations of Density in Spruce Wood.

FOREST PRODUCTS LABORATORIES OF CANADA OTTAWA, ONT.

are mathematically remote, because of the small number of such logs. The figures give a fair indication of the degree of variability of white spruce, and show how the "average" quality of any material is determined by the grouping of individual samples about the mean in somewhat similar arrangement and in accord with the law of variation.

Variation encountered in wood of Engelmann spruce is shown in Figure 4. The samples used for test were small specimens one inch thick in radial dimension, selected from logs so as to represent proportionally the wood in all parts of the log. There is notable similarity between this and the white spruce variation charts based upon log sections. The slightly wider range of extreme variation in this instance is due to the fact that the size of the samples of Engelmann spruce is smaller, and, therefore, permits registering most of the variations to be found in different parts of the log. Use of very large samples, tending to combine in one specimen the material of 10 or 20 smaller samples, would naturally tend to decrease the range of variation.

Compression-wood, a Defect that Causes High Density in Softwoods

Such typical variations in density of wood according to the rate of growth or the position in the tree as may be the rule for normal wood meet exceptions in the case of compression-wood. Compression-wood is a defect that occurs frequently in the trunk of all species of softwoods and consists of areas of abnormally dense wood. In freshly felled logs it may be detected by its dark reddish colour and its typically eccentric occurrence in patches on one side of the

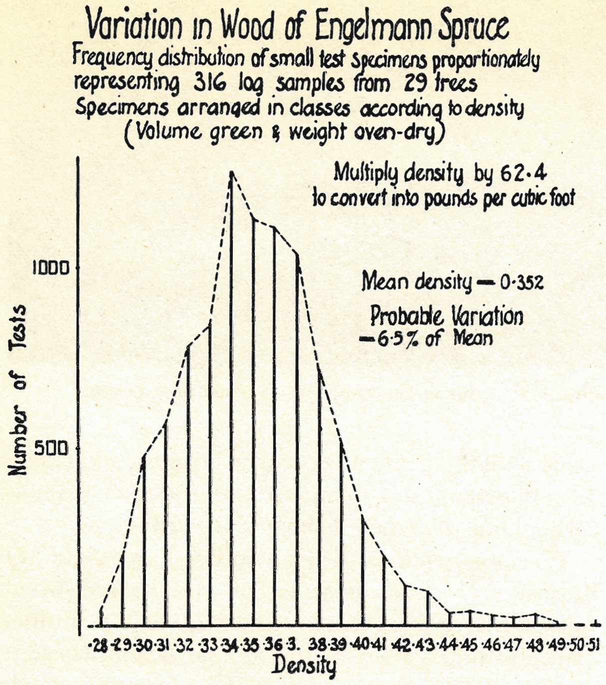


FIGURE 4.—Diagram Showing Variation in the Wood of Engelmann Spruce.

tree, where the annual layers of the compression-wood are abnormally wide and have the appearance of an unusually large proportion of summer-wood (Plate 32). The dark colour of this type of wood is due to the fact that its cell walls are abnormally thick, which makes compression-wood abnormally hard and dense.

Compression-wood owes its name to the fact that it occurs normally in conifers on the lower side of lateral branches, which is the side under compressive stress from supporting the weight of the branch. When it occurs in the trunk of the tree (and not merely in branches) it may constitute a defect. If young saplings are grown in an inclined position or are bent so as to compress one side appreciably, the formation of compression-wood on the lower side of the trunk may be induced. It is always to be found on the lower sides of the trunks of leaning trees and is particularly prevalent in trees exposed to wind. It is of interest that where prevailing winds blow in one general direction compression-wood is found on the lee side of the tree trunks (i.e., the side compressed by the winds) but if trees are exposed to winds from all sides, compression-wood may be formed all around the trunk. This wood is also known by such names as "glassywood", "redwood" or even by its German name "rotholz".

While the thick cell walls of compression-wood may often give it added resistance to compression along the grain, imperfect adhesion between the neighbouring cells causes it to be weak in tension. Wood containing compression-wood cannot, therefore, be safely used in structural members subject to bending or impact, because of its susceptibility to sudden brash fractures across the grain. Moreover, unlike normal wood, it shrinks excessively along the grain during drying.

This abnormal type of dimensional change is likely to cause boards to bow and twist when streaks of compression-wood shrink along the grain and set up local stresses on one edge or face of the piece of wood (Plates 33 and 34). Where the streaks of compression-wood are not sufficient to cause the wooden member to bow, the weakness of these defective streaks under tension may cause abrupt breaks across the grain, merely as a result of the longitudinal stresses exerted in the compression-wood during drying (Plate 35).

Excessive compression-wood is a defect in pulpwood as well as in wood employed for structural purposes. If used for mechanical pulp, its brittle structure causes it to yield a broken and weak fibre that lacks cohesive strength, while in chemical pulping, beating only weakens pulp from compression-wood by breaking its component fibres into short pieces. Since such wood has higher lignin content than normal wood, its usefulness for high-quality pulp may be considerably restricted (32).

In tests carried out by the Ottawa Laboratory on spruce and balsam fir of Eastern Canada (18), compression-wood was found very prevalent in stands exposed to heavy winds. Trees of spruce and balsam fir growing on slopes steeper than some 20 degrees were found to have large amounts of compression-wood from butts to tops of trees and it is probable that the same situation may hold with respect to other softwood species. Although compression-wood generally loses some of its distinctive dark red colour on drying, it darkens again on wetting and, particularly in light-coloured woods, its presence may be demonstrated by application of water to seasoned material. Its microscopic structure is, of course, characteristic.

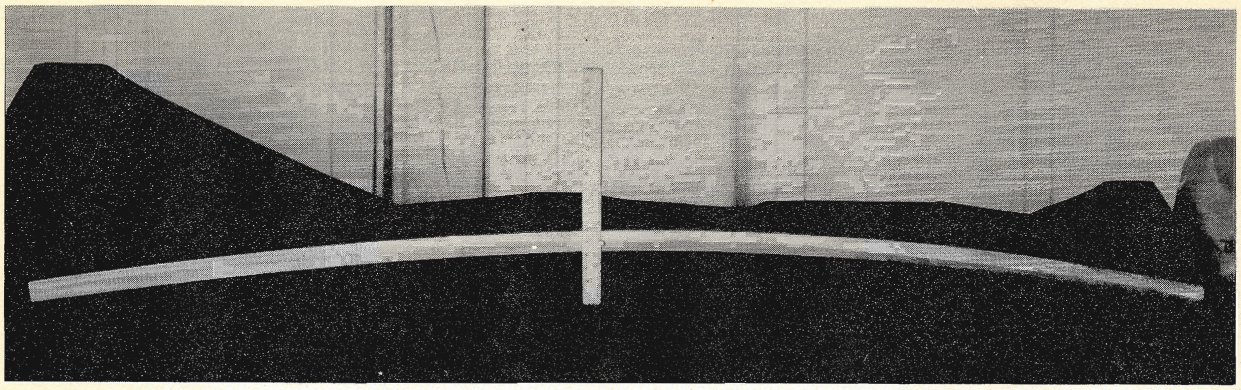


PLATE 34.—"Bowing" in Spruce Scantling. Caused by longitudinal shrinkage of compression-wood on one side.

Probably very few coniferous trees are completely free from compression-wood in their trunks, for even in trees where its presence is insignificant it often occurs in a few annual layers near the ground level close to the centre of the trunk, as though formed when the tree was a young sapling, perhaps bent under loads of snow and ice sufficient to cause the formation of this defect. In some trees, compression-wood may occur in mere traces sufficient only to make the summer-wood a little more than usually prominent, but in severe manifestations the annual layers are darkened in both spring-wood and summer-wood and usually are widened. It is typical to find compression wood on one side of the trunk only, so that abnormally wide rings of compression-wood give the trunk an eccentric cross-section (Plate 32). In severe cases, compression-wood often extends throughout the whole length of the trunk.

The cross-sections of small spruce logs (Plate 32) illustrate (1) the presence of compression-wood in a slight degree sufficient to accentuate the outlines of the summer-wood in the annual layers where it occurs; (2) a medium amount of compression-wood, where it is mainly confined to one side of the piece and where its prevalence in neighbouring annual layers varies from the just visible stage to that in which the whole annual layer is widened, and (3) where the compression-wood is so strongly developed that it causes eccentric growth and occupies upwards of half the log.

PLATE 35.—Cross-break in Compression-wood in Box Shook.

The thick-walled cells of compression-wood are rounded in outline, unlike the more nearly rectangular or polygonal cross-sections of the cells of normal wood, as magnified cross-sections show. Whereas the cells of normal wood fit closely together in tight contact, with a thin layer of cementing substance (the so-called middle lamella) between them, the rounded outline of the heavy-walled cells of compression-wood permits only partial contact along the faces of neighbouring cells, so that it contains many intercellular spaces. When compression-wood is subjected to tension parallel with the grain, the fibres may be drawn apart with much less force than is required to cause similar separation in a sample of normal wood, where the fibres are firmly united by contact along the full width of the faces of the cells. The comparative weakness of compression-wood in bending, tension, and impact, and its separation in abrupt failures across the grain without splintering, is therefore understandable. The simple reason is that its stiff fibres are so imperfectly bonded that the wood must necessarily exhibit relatively low cohesion.

Compression-wood shrinks and swells parallel to the direction of its fibres, owing to the fact that these thick-walled cells are composed mainly of spirally arranged fibrils slanted at fairly steep angles around the cell wall. When these spiral coils shrink through loss of moisture, the components of the coils draw closer together and thereby shorten the length of the cell. Compression-wood therefore shrinks along the grain, i.e., along the direction of the cells.

Variation in Hardwoods

In hardwoods, variation in density seems greatest in the ring-porous species, where there is great contrast in texture between the band of large cavities of the spring pores and the band of heavy fibres in the summer-wood. From the evidence at hand, the general statement may be made that extremes in the rate of growth do not normally produce the heaviest timber.

The ring-porous woods commence the growing season by forming a layer of large pores. Even when growth is extremely slow, this ring of large pores occurs. If the growth of the annual layer stops without the addition of much fibrous wood, it is obvious that such slow growth, which produces but little dense fibrous material after forming the row of large vessel cavities, results in the production of wood containing an unusually large proportion of air spaces (Plate 25). Ring-porous hardwoods of excessively slow growth are for this reason lighter in weight than is usual for the species, and correspondingly weak.

When, on the other hand, ring-porous woods form extremely wide rings, the density is likely to be below the maximum, not because the wood contains numerous large vessel cavities, but because the fibrous elements of such wood are often relatively thin-walled, and thereby cause an unduly large ratio of cell cavities to cell walls. The effect of variations in rate of growth on the density of certain ring-porous wood, as typified by ash and hickory, has been mentioned by various investigators (14, 24, 31), and in some instances observation of the width of growth-rings may be useful in selecting material of the type desired. The width of growth-rings may not, however, always be a reliable indicator of the density of ring-porous woods, since the proportion of thick-walled fibres may be influenced by numerous factors that affect the formation of wood, but which do not necessarily affect the rate of diameter growth.

In view of the variety of influences that may have a part in the formation of wood, it is not surprising that wood of the same growth-rate from different regions may have different properties. Soil conditions, moisture, temperature, and density of the surrounding stand are a few of the important variable factors that contribute to the growth and formation of trees, so that no absolute rule can be formulated for selection of wood according to the width of growth-rings. It is probable also that the influence of maturity in age or of size on the density of wood, as mentioned in softwoods, often has a somewhat similar effect in hardwoods, as such instances have been noted in various investigations (9).

Diffuse-porous hardwoods lack the row of extremely large pores that characterize the early wood of the annual layer of ring-porous wood, and in this sense are the more uniform in structure. The heavier native woods of this type, such as birch and maple, seem much less subject to significant variations in structure and density than the ring-porous woods. The lighter of the diffuse-porous hardwoods, however, show some variations in density that appear to be related to variations in rate of growth. Wood of a medium growth-rate in these species tends to be somewhat denser than that of extremely fast or extremely slow growth. Instances of the practical

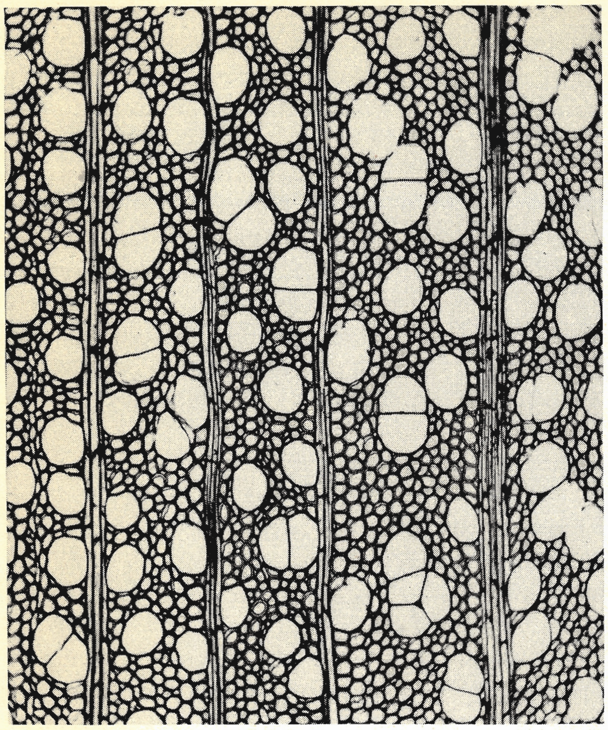


Plate 36.—"Hard" Yellow Poplar (× 65).

Weight per cubic foot, air-dry, 31 pounds. Rate of growth, about 9 rings per inch.

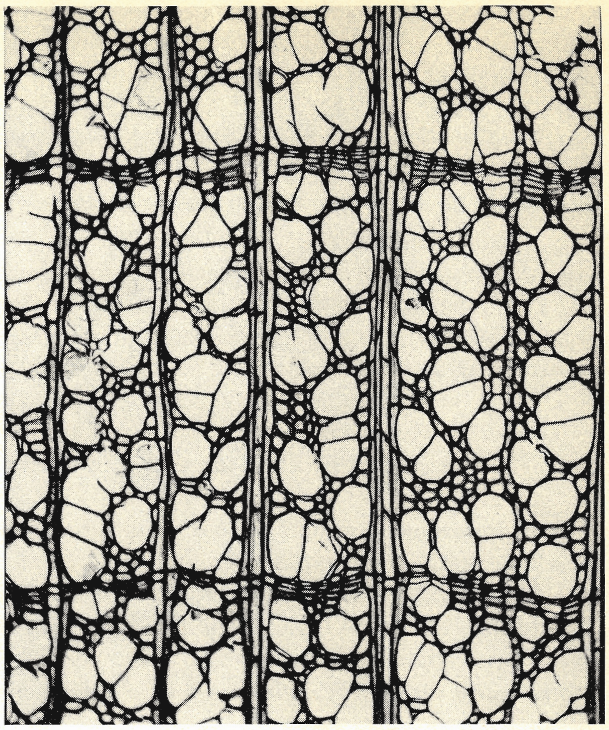


Plate 37.—"Soft" Yellow Poplar (× 65).

Weight per cubic foot, air-dry, 25.5 pounds. Rate of growth, 27 rings per inch.

The soft type, although weaker than the other, may be preferred, as the harder, heavier, and stronger wood shows more tendency to check. Note the comparatively large proportion of air spaces in the lighter type of wood.

importance of such variations are continually noted. For example, in connection with the so-called yellow poplar or "whitewood" (*Liriodendron tulipifera*), instances are reported where wood of slow growth and relatively low density is preferred to that with wide growth-rings and higher density, because the material of light weight is less subject than heavy wood to changes in volume due to changes in moisture content[7]. The structure of both the heavy wood and the light wood reported by Stokes (38) is illustrated in Plates 36 and 37, where it is evident that the light material has the larger proportion of air spaces, owing to the closer grouping of the pores. The lighter type of wood showed the least tendency to shrink and form checks when in service.

Abnormal wood is sometimes found in trees whose rate of growth appears entirely normal. Such instances have been noted in basswood, where the presence of abnormally light-weight wood has been found to be due to a larger proportion of pores than is normal. Such wood is of the same species as the normal wood and had a similar rate of growth. Its different quality may be varietal or may possibly be due to the growing conditions. Investigations of the quality of wood produced by various growing conditions may be expected to furnish information of value in silvicultural studies relating to control over the quality of timber, not only as regards rate of growth, but also in respect to those properties of wood not related to the width of the annual rings.

An abnormality found in hardwoods on the upper side of both branches and trunks of leaning trees, is known as "tension wood". It is typically denser than normal wood, often occurs in streaks conspicuous for lustre and a tendency to show "woolly" surfaces when sawn, and exhibits abnormal shrinkage along the grain. More difficult to detect than the compression-wood of conifers (q.v.), its origin and occurrence need further investigation.

[7] See reference in subsequent pages to shrinkage and swelling of wood in response to changes of moisture content.

EFFECTS OF STRUCTURAL CHARACTERISTICS ON THE PROPERTIES OF WOOD

Importance of Characteristics Other than Strength

THE aggregate effect of structural characteristics of wood on its properties has already been implied, and it has been shown that woods containing a large proportion of cells that are thick-walled tend to be heavier, and therefore stronger, than woods composed of cells with thin walls.

Strength, however, may be relatively unimportant in many uses, although in most cases it will be an important, if not a deciding factor in selecting timber for a particular purpose. There are, however, other important characteristics of wood which affect its utility and its market value.

Many woods are of extreme utility and yet are comparatively low in strength. Probably white pine (*Pinus Strobus* L.) is one of the best-known types of wood finding practically universal application, because its general properties are highly desirable, although its strength is below that of many less valuable timbers. Ease in working, uniformity, and stability are valuable technical qualities that are often more desirable than great mechanical strength, and it is, therefore, important to investigate the relation between structure and some of these characteristics of timber.

Dimensional Changes in Wood

One of the difficulties encountered in the use of wood is that it has considerable affinity for moisture. Dry wood will absorb water from moist air with consequent swelling, and if conditions then change so that the air surrounding the wood becomes sufficiently dry, it will withdraw moisture from the wood, which will then shrink. Continually fluctuating atmospheric conditions cause corresponding changes in the moisture content of wood that is exposed to the atmosphere. If the drying capacity of the air remains the same, the absorptive tendency of the wood in time becomes counterbalanced by the evaporative capacity of the air. In such a condition of equilibrium, the moisture content of the wood of course remains constant, so that such wood undergoes no volumetric change. Thus, one of the objects of seasoning lumber is to bring it to a moisture content that will be near the equilibrium point for the atmospheric conditions in which the wood will be used, in order to minimize as much as possible shrinking and swelling of the wood after it has been installed.

The wood of freshly felled trees may be more than half water by weight[8], and this excessive moisture must be removed by a seasoning process. Lumber that is seasoned in outdoor piles will not, in most parts of Canada, ordinarily reach an aggregate moisture content of less than about 12 per cent when thoroughly air-dry, so if a lower moisture content is required, the stock must be subjected to kiln-drying processes employing properly conditioned air.

Wood does not commence shrinking until its moisture content is reduced below the fibre-saturation point[9], which seems to be at a moisture content of about 25 per cent or more for most woods. In drying lumber, especially thick lumber, the outside is likely to reach the fibre-saturation point, and to begin shrinking, while the moisture content of the interior is still above this point. However, the reduction in volume of wood due to loss of moisture content is generally considered to commence as the moisture content falls below the fibre-saturation point, since the shrinkage of wood is due to the contraction of the cell walls as the moisture in the walls evaporates.

The shrinkage of the cell walls causes a reduction in the original diameter of the hollow cells, but does not very greatly affect their length. This peculiarity of shrinkage is due to the fact that the individual particles composing the cell walls are made up of long crystals arranged for the most part parallel to or slightly inclined from the long axis (8, 30) of the cell. In the growing tree, the cell walls are saturated with water, which apparently is present in films between the crystals, so that, when the tree has been felled and its wood dries, this water is removed, and the component crystals necessarily draw closer

[8] For convenience of the lumber industry, it has been found desirable to express the moisture content of wood as a percentage of the weight of oven-dry wood. Thus, a piece of wood that is one-half water by weight is said to have a moisture content of 100 per cent, and higher moisture contents are not uncommon in freshly felled wood.

[9] In wet wood, water saturates the cell walls and is also present in the cell cavities. Wood is said to be at the fibre-saturation point when it contains just enough water to saturate the cell walls without any free water in the cell cavities. If the moisture content is increased above this point the additional water obviously must be accommodated in the cavities; or, if that content be decreased, the moisture removed must come from that saturating the cell walls. No changes in volume ordinarily accompany changes of moisture content above the fibre-saturation point.

together. The fibrous cell, therefore, shrinks much more in diameter than in length, because of the general longitudinal arrangement of long crystalline units, separated laterally by water films which decrease in thickness as the water evaporates in drying. The process is reversible, as comparatively dry cell walls take up additional water when exposed to water vapour or liquid. In view of this mechanism, changes in the dimensions of wood take place chiefly across the grain, that is to say, at right angles to the direction of the fibrous cells of wood.

The usual method of comparing the shrinkage to which various woods are susceptible is to measure the total contraction undergone in shrinking from the fully expanded condition (at saturation) to the oven-dry condition. The amount of shrinkage varies in different kinds of wood, and may be influenced somewhat by methods of drying. In general, the denser woods shrink more than the lighter, although there are notable exceptions. As there may be considerable variation in density of wood, even in the same species, so there is a corresponding variation in shrinkage.

Eastern cedar (*Thuja occidentalis* L.), which shrinks somewhat less than 7 per cent of its original volume in drying from the saturated to the oven-dry condition, has the least shrinkage of the Canadian woods so far tested.

The shrinkage is not equal in all directions across the grain, but is greatest in the tangential direction and least in the radial direction. While the relation of radial shrinkage to tangential shrinkage varies considerably in different woods, the average tangential shrinkage for all woods is nearly twice the radial shrinkage. The average radial shrinkage of the different Canadian woods ranges from about 1.7 per cent to 6.7 per cent. The average tangential shrinkage ranges from 3.7 per cent to over 10 per cent. The slight longitudinal shrinkage is generally disregarded in practice, as its total amount (from saturated to oven-dry condition) is only about 0.1 to 0.2 of 1 per cent (25). It should be noted that the figures for shrinkage are greater than the shrinkages encountered in practice, since wood is never used in the oven-dry condition. In reaching a thoroughly air-dry condition lumber undergoes about half of the total possible shrinkage, while lumber that is kiln-dried may undergo three-quarters of the total possible shrinkage.

The structure and formation of wood prevents uniformity of shrinkage across the grain. The rays in wood are bands of cells with their axes in a radial direction, and these do not tend to shrink much in length, so that they tend to resist the radial shrinkage of the wood fibres and to favour longitudinal shrinkage. Furthermore, the shrinkage in width of the rays augments the tangential shrinkage of wood.

As the least shrinkage across the grain takes place in a radial direction, and the maximum shrinkage is found at right angles to this in the tangential direction, various amounts and degrees of dimensional change are to be expected in pieces of wood, according to the position which they originally occupied in the log. Square pieces of timber cut from green lumber may, therefore, change their cross-section in drying to something like the conventional diamond shape, and round dowels may become elliptical. The cupping of plain or flat-sawed lumber with the concave side of the surface where the greatest contraction occurs is also explained, as is the twisting of long pieces that are not straight-grained (Figure 5).

Another cause of unequal shrinkage may be found in pieces of wood containing regions of different density. In such pieces the heavier regions normally undergo more shrinkage than the others.

Excessive longitudinal shrinkage attending the drying of wood occurs in the so-called compression-wood of softwoods and it has also been described (25) in hardwoods that are light in weight for the species. In both instances, such abnormality in shrinkage is due to the abnormal structure. Compression-wood is much denser than normal wood. It is composed of cells with unusually thick walls and with the cell wall material arranged in fibrils that spiral about the axis of the cell at a relatively large angle. The individual particles of these spirally arranged fibrils tend to draw together in drying and therefore exert a component force in contracting the length of the cells. Imagine, for example, a spiral spring made of hygroscopic material arranged so that each individual coil rests against its neighbour. If the material of such a spring were to shrink slightly, the height of the coil would be reduced by an amount equal to the total of the changes in dimension of each individual coil. A structural arrangement of the cell wall of the abnormally light hardwoods that is somewhat similar to that in compression-wood probably explains the unduly large changes in longitudinal dimensions of

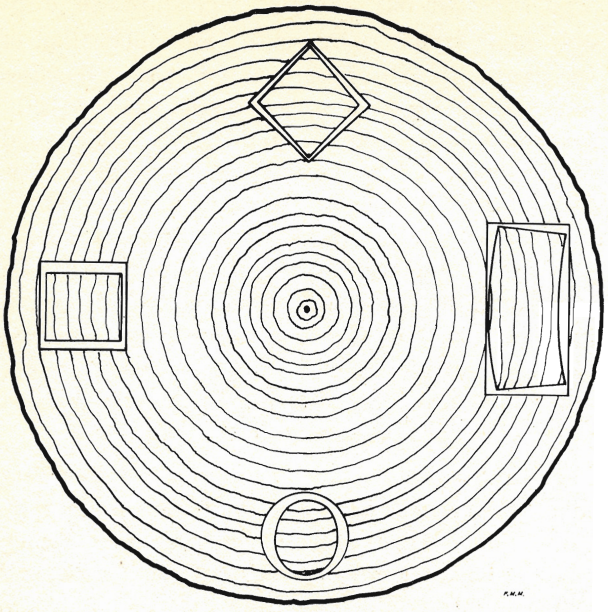


FIGURE 5.—Diagram Illustrating the Shrinkage of Wood Across the Grain.

The clear space represents, in each case, the shrinkage in drying from green to oven-dry condition.

such timber. One very obvious difference between the two classes of material is that such light hardwoods have abnormally thin cell walls, whereas the cell walls in compression-wood are unusually thick. Recent investigations (35) indicate that the outer material of the walls of normal wood cells is composed of fibrils that incline at greater angles to the axis of the cell than do the fibrils towards the inside of the wall. Since the relative thinness of cell walls of the abnormally light woods that show extreme longitudinal shrinkage may be regarded as due to poor or interrupted development, it may be that the preponderance of spirally arranged fibrils in cell walls of such wood is the explanation of its abnormal longitudinal shrinkage. It is also a reasonable inference that the tendency of the rays to shrink in the direction of the fibres might result in greater than normal longitudinal shrinkage in woods that are relatively light and weak, and therefore less resistant to this contractile stress than woods of normal density.

Compression-wood is an exception to the rule that the shrinkage of wood at right angles to the direction of the fibres is related to the density. Although compression-wood is heavier than normal wood, its shrinkage across the grain is less than would be expected for the average normal wood of the same density.

Basswood (*Tilia* sp.) is an example of a lightweight wood that shows an unusually large amount of shrinkage in drying from saturation to the oven-dry state. There are other exceptions among woods that are relatively heavy and yet show proportionately little shrinkage. The general effect of the density of wood upon its shrinkage has, however, been commonly noted. The shrinkage factors (shrinkage factor is the amount of shrinkage in drying from saturation to the oven-dry state, expressed as a percentage of the original dimension measured when green) of North American woods are expressed in the "International Critical Tables" (21) as functions of the density. The factor for radial shrinkage obtained as an average for all commercial woods of the United States is given as 9.1 times the specific gravity of the wood (specific gravity based upon the green volume and the oven-dry weight), and the tangential shrinkage as 16.3 times this specific gravity. It is of interest that the average factors for Canadian woods (35) tested at the Laboratories approximate these figures. A wood of specific gravity .40 would, therefore, have radial shrinkage of about 3.6 per cent and tangential shrinkage of about 6.5 per cent if it conformed to this rule.

The shrinkage factors noted were obtained as an average for measurements of both softwoods and hardwoods. Softwoods in general show less actual shrinkage in width and thickness of boards of comparable nature than do the hardwoods, because of the lower average density of the softwoods. However, when the shrinkage factors of the two groups are compared on the basis of relative density (so far as one may judge from the shrinkage factors recorded for the various woods so far tested), the softwoods show slightly greater shrinkage for their density.

Unequal Shrinkage of Wood and Some of its Practical Effects

The stresses in wood caused by changes of moisture content depend somewhat on the size of the piece and the position which it occupied in the tree. From the foregoing discussion, it will be obvious that

quarter-sawn boards[10] shrink less in width than plain-sawn[11] material. There is, of course, a great deal of lumber that cannot be truly quarter-sawn in pieces of usable size, and this is particularly evident in the conversion of small logs. When, therefore, either truly quartered or truly flat-sawn wood is required for the most exacting uses, material from large logs is at a premium. In such truly quarter-sawn material, the greatest shrinkage stresses (tangential to the growth-rings) are parallel with the edges of the piece and the least stresses are parallel with the faces, while in truly flat-sawn wood the situation is reversed and the greatest shrinkage takes place parallel with the faces. Material containing annual rings that show appreciable curvature may have the tendency to shrink more on one face than the other, and so may tend to cup slightly in drying.

For ordinary use, quartered and plain lumber of common species may not be separated if the wood has no figure, or if the use of the wood does not warrant it, since the modern practice of drying wood to the moisture content it would naturally attain under the average conditions of its use ensures the minimum of dimensional changes after installation. If the wood does not change its dimensions appreciably after installation, it obviously does not matter what its capacity for such change may be.

In laminated construction of the highest type, however, it has been the custom to select individual members for uniformity and with particular regard to obtaining the wood that will undergo the least possible dimensional changes. Especially in material to be used under fluctuating atmospheric conditions is it advisable to use quarter-sawn stock for the laminae and never to glue a plain-sawn member to a quarter-sawn one, as such a procedure will probably cause failure at the joint. The application of the glue moistens the surfaces of the wood, and causes a corresponding tendency to expand, and the subsequent drying causes unequal stresses in the wood of the unlike neighbouring faces, since the dimensional change in the plain face is greater than in the quartered face. A typical instance of failure at the joint between quarter-sawn and plain members of a laminated aeroplane spar is on record. It would have been best in this case to use only quartered material, but the use of flat-sawn laminae throughout would have been better than the combination of the two kinds of material in the same piece.

The indiscriminate use of pieces of wood of very different densities, even if of the same species, may cause similar defects in laminated structures. Heavy wood, having the greatest capacity for dimensional changes, shrinks the most, and may contribute to failure of the joint between the heavy and light laminae, or may cause warping and cupping if combined with unduly light-weight members in thin assemblies of this construction.

In current laminated construction of building timber, and of arches built up from combinations of thin boards held together by nails and adhesive, less critical selection and matching of the material is, of course, permissible than in laminated members of small size, where the influence of a single component might exert adverse effects on the whole assembly.

CHARACTERISTICS AFFECTING GENERAL USES OF WOOD

SOFTWOODS are used much more extensively than hardwoods, and this preference is due both to their relative abundance and their wide adaptability. It would be difficult to present a brief description that would adequately define the range of usefulness of softwoods.

The common employment of such material in engineering works and in general building construction ordinarily accounts for a large proportion of the softwood supplies. These woods, however, also find more specialized uses as interior finish, sash and door material, shingles, and flooring. Large quantities of softwood are employed in the manufacture of shipping containers, especially crates, boxes, and baskets, where the maximum of strength and

[10] Truly quarter-sawn boards have faces that in the log occupied a radial plane parallel with the rays, i.e., in the radial plane passing from the pith or centre of growth, toward the outside of the log. "Quartered", "vertical-grain", "edge-grain", "rift-sawn", and "rift-grain" are synonymous.

[11] Plain-sawn boards have faces at approximately right angles to the rays, i.e., approximating the plane that is tangential to the growth-rings. Such boards are sometimes called "flat-sawn", "flat-grain", "tangential-grain", "slash-grain", or sometimes "bastard-grain". The term "bastard-grain", however, appears to be applied in some localities to lumber that is about halfway between a true vertical-grain and a true flat-grain. It is the common practice, however, when figure is not required, to classify as "quartered" stock, boards with faces inclined not more than 45 degrees from a true radial plane. In some old grading rules even the term "angle-grain" has been suggested as a classification for boards with faces inclined not less than 45 degrees nor more than 65 degrees from a radial plane.

minimum of weight are often required. Adequate mention of the many "specialty uses" where certain softwoods are employed because of special qualities desired by the trade would make a long list that need not be itemized here (see Section "Classified Uses", Chapter 2). In addition to use as lumber, softwoods are by far the most important pulpwoods in Canada.

If hardwoods are on the whole used in much smaller amounts than softwoods, their use in cabinet-work, turnery, panelling, and decorative work generally has made species such as oak, walnut, mahogany, birch, and maple familiar wherever wood is used. While hardwoods are used widely in such fields, they also find a great variety of other special uses because of qualities of strength or toughness and resistance to abrasion and shock. In flooring, vehicle construction, tight cooperage, and particularly in sporting goods and similar products of very exacting requirements, the mechanical qualities of certain hardwoods make them the pre-eminent materials. Certain hardwoods are being used increasingly for pulp.

Forest-grown softwoods with relatively long, clear trunks furnish the large timbers essential in engineering work. The heavier softwoods, which have the greater mechanical strength, are naturally the ones most suitable for heavy construction, although in some instances the occurrence of large knots in structural material of the lower grades of wood may render beams of fairly heavy species somewhat weaker than similar material of lighter woods with smaller or fewer knots.

Density is a characteristic of importance, because it is rather directly dependent on the thickness of the cell walls. Bearing in mind the specific structure of each kind of wood, the basic density may be regarded as an index of the average thickness of the cell walls, and therefore a fair indication of the physical properties. As density may be easily measured, its determination has come to be regarded as one of the significant stages in the appraisal of wood, and no list of tests or technical description of wood can be considered complete unless density is included. Density is so widely recognized as indicative of the general strength and shrinkage characteristics manifested by the common woods (24, 31) that tables showing mechanical properties, hardness, and shrinkage of various timbers as functions of their average density have been given wide circulation (21).

It is natural, therefore, when wood of particularly high strength is required for special purposes, that selection should be made on the basis of high density. Specifications for such specialty stock commonly provide that the material shall meet specified requirements of high density, freedom from defects (whether primary or those incurred during manufacture), and certain average width of annual rings. In the selection of such wood, experienced inspectors of specialty stock try to detect indications of brash[12] or brittle wood by visual examination and by "pick" tests to discover whether or not the wood has sufficient fibrous "toughness" to permit peeling small slivers from the surface. Wood found to be brash is, of course, inacceptable where good mechanical properties are required.

Brash Wood

As previously indicated, weak wood of low density may be detected by certain well-marked anatomical peculiarities. On the other hand, compression-wood of softwoods provides instances where wood of high density may, because of structural peculiarities, be brash and exceptionally weak in resistance to tension. However, in addition to these easily recognized types of weak material, there is a condition of wood that causes it to be brash without greatly affecting the appearance. Inspectors of wood for aircraft are particularly alert to detect this type of abnormal material.

In examining wood that has undergone brash failure in service and yet shows no obvious reasons for its weakness on careful visual inspection, use of the microscope may be required to establish with certainty the reasons for brashness. Such wood usually shows many incipient microscopic breaks across the walls of the cells, such as compression parallel with grain might cause in slightly "telescoping" the fibres. The tensile strength and shock resistance of such material is seriously reduced since, under tension, the wood fails because the cell walls are easily pulled apart in the regions of these incipient breaks (Plates 38 and 39). Used for pulpwood, such material produces weak pulp because the fibres tend to break into short pieces.

[12] *Brashness* may be defined as a condition of wood characterized by low resistance to shock and an abrupt failure across the grain without splintering.

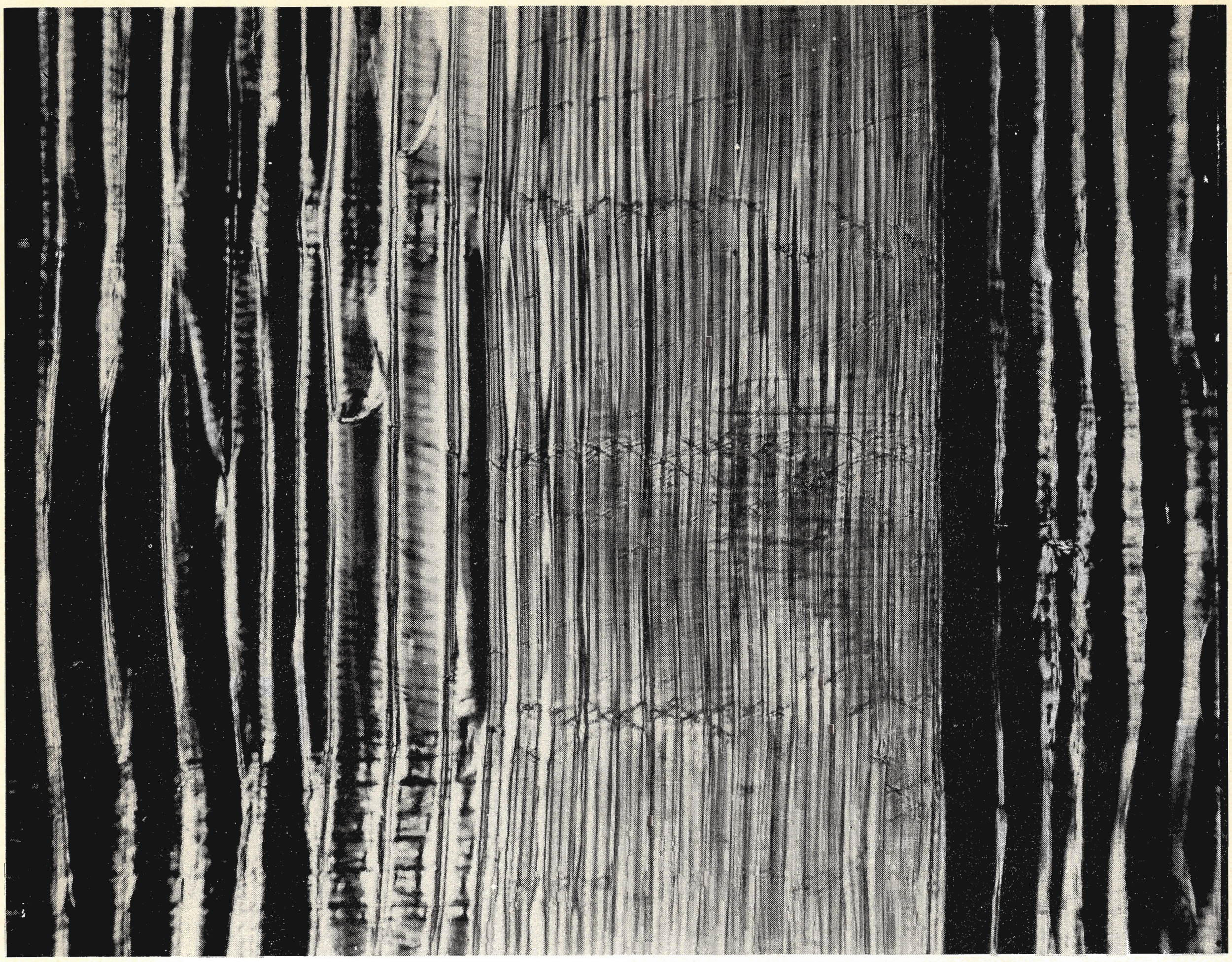


PLATE 38.—Enlarged Section of Brash Wood, Showing Typical Breaks (× 200).

This "invisible" defect seems to be produced by local concentration of compressive stresses while the trees are standing, for it is obvious that heavy accumulations of snow and the action of even moderate wind could produce enough compression in local areas of the trunks of large trees to "telescope" the cell walls.

Brash wood of this type may be detected by observing its reaction to cutting tools. Because of its liability to break sharply across the grain, such wood is frequently detected by observing the sawn ends of logs or smaller pieces which inspectors describe as having a "punky" appearance, even though the colour is good and the wood is not decayed. This typical appearance of the sawn ends is caused by the wood being broken, rather than cut, by the saw teeth. Observation of such surfaces with a small magnifier shows that much of the area exhibits cleanly broken cross-sections of the cells with the minimum of fibrous slivers. The fact that long slivers cannot be peeled from such wood because of its typical short "cheesy" fracture is an identifying feature that assists in its detection.

PERMEABILITY OF WOOD

Relation of Permeability to Preservative Processes

ONE of the problems of wood construction arises from the susceptibility of many woods to decay in certain conditions of use. This necessitates the preservative treatment of such woods when used in situations that favour decay, so that the service life of the timber may be increased greatly beyond the period normally expected from untreated wood (see Chapters 6 and 7).

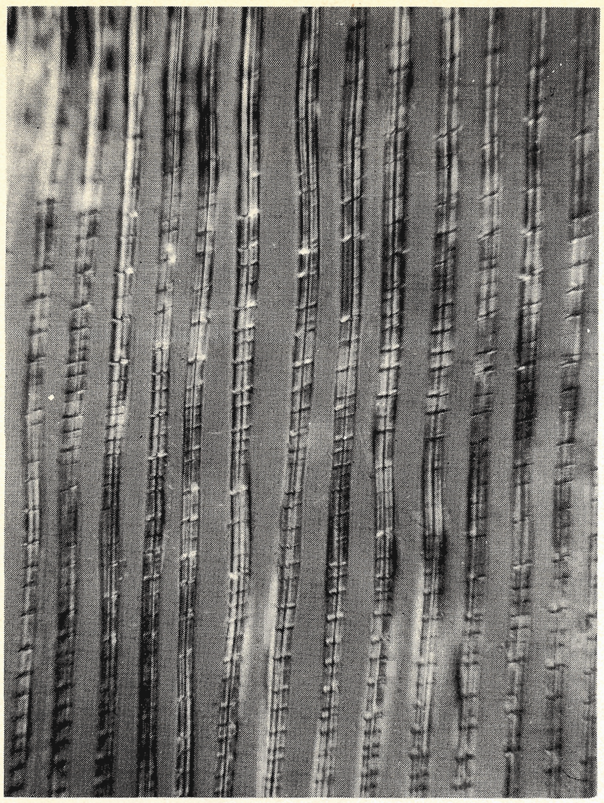


PLATE 39.—Magnified Section of Brash Wood, Showing Incipient Breaks in Cell Walls (× 250).

The porous nature of wood permits its impregnation under pressure with fluid preservatives which penetrate the cell cavities and intercellular spaces. In view of the uniform orientation of the tubular cells composing wood, by far the greatest flow of preservative takes place along the grain. Sapwood is easily penetrated, but the heartwood of some species may be relatively impervious, resisting the penetration of fluids even when these are introduced under relatively high pressures.

The comparative ease with which sapwood takes preservative is utilized to advantage in treating material in the round, such as poles and posts, which have their sapwood intact. The sapwood of such material absorbs the preservative so readily as to distinguish it sharply from the heartwood in species where the latter type of wood is difficult to penetrate. Such a distribution of preservative material in the outer region of the pole is generally sufficient to afford satisfactory protection against decay, since the preservative treatment is generally accomplished at high temperatures, which, if sufficiently prolonged, kill decay-producing organisms in the interior of the wood, even if this region is not actually reached by the preservative.

When surfaced timbers having exposed heartwood are to be treated, it may be necessary to incise the refractory surfaces at close intervals before treatment. After such preparation the preserving liquids readily penetrate the incisions, which are of the required depth and spacing to ensure that the forced penetration (which is chiefly along the grain) spreads preservative to a proper depth in each piece of material (28).

The reasons for the differences in permeability of sapwood and heartwood are to be found in certain slight but important structural differences that generally characterize conductive cells in these two regions of the tree. In the softwoods, the hollow cells are separated from each other by a thin membrane, and the passage of sap from one cell to another takes place through openings in the walls of neighbouring cells which allow access of the cell contents to the

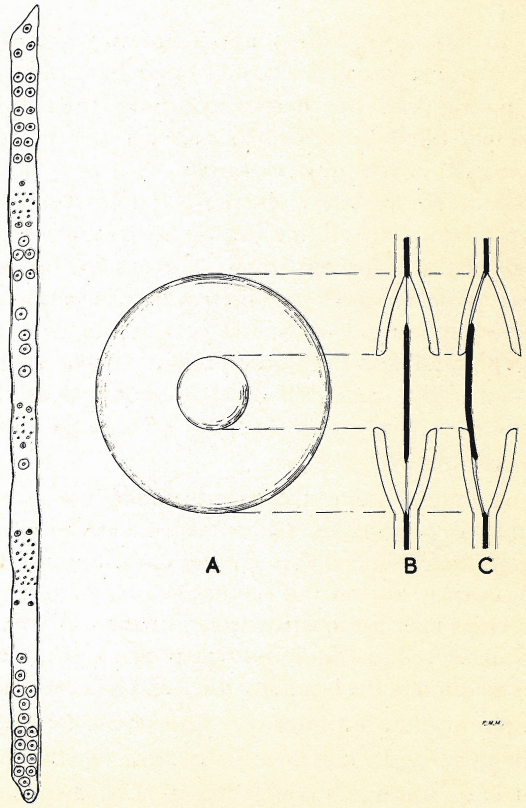


FIGURE 6.—Bordered Pits in Softwood Tracheid.
A. Bordered pit—face view.
B. " " of sapwood in section
C. " " of heartwood in section

common membrane. This membrane, permeable by water and even by very finely divided solids in suspension (1) permits the passage of sap from cell to cell. Walls of sap-conducting cells are slightly depressed in a circular area surrounding the openings, or "pits", so that the depressed region presents the appearance of a comparatively large border around the small opening. Hence the name "bordered pits" has been applied to these openings between the water-conducting cells of softwoods. The pit membrane which separates the neighbouring cells has a thickened impermeable area (called the torus) in the centre opposite the pit openings, but as the membrane occupies a median position in the pit chamber of active sap-conducting tissue, the torus does not interfere with the passage of sap. In heartwood, however, the pit membrane generally appears to change its position so that the torus is pressed against one of the pit openings (Figure 6), with sufficient force to prevent or greatly limit the flow of liquid (22).

In hardwoods, the water-conducting channels in the outer sapwood are usually open, but, in the inner sapwood and the heartwood, may become completely filled by tyloses (ingrowths of cells) or by deposits of gummy materials which occupy the cavities completely or in part. These obstructions, when completely filling the pores, prevent the passage of liquid preservatives along them, but under the pressures used in preservative treatments of wood, the liquids may find other passages. Under such conditions the lighter woods appear generally more easily penetrated than very heavy ones. In all woods, regions where decay is present are likely to be readily permeable.

In preservative treatment under pressure, the general practice is to remove excessive moisture from the timbers before forcing the preservative into the wood, so that the presence of water in the cell cavities may not obstruct penetration. When wood is immersed in liquid under pressure, the rate of absorption of the liquid by the wood is comparatively rapid at first, but later slows considerably. Experiments carried out in these Laboratories on the passage of water through small specimens of hardwood in the direction of the grain show a similar rapid decrease from a relatively high original rate of flow to a slower and fairly constant rate; this would indicate that enough pressure is built up in the wood to retard flow along the vessels, even when the discharge end of the wood specimen is freely exposed. If the small specimens are high in moisture content, the initial rate of flow is generally much less than in specimens of low moisture content. Similar investigations of the flow of liquids in small laboratory specimens have been reported for softwoods (3, 39). The penetration of liquids into wood has an important bearing on the proper cooking of pulpwood, the sinkage of water-driven logs, the selection of tight-cooperage stock, and other problems, as well as the preservative treatment of timber.

Relation of Permeability to Sinkage of Water-Driven Logs

In transporting logs to the mill, they must often be floated for long distances, during which process losses from sinking are frequently considerable.

From examination of logs floated for various periods at the Laboratories, it was found that most of the water absorbed enters the sapwood in the case of species whose heartwood and sapwood are sharply defined. Thus, in sound logs of spruce and jack pine very little water entered the heartwood except near the ends of the logs, whereas the sapwood became readily saturated. In balsam fir, which frequently does not have a well-defined area of heartwood, there is likely to be penetration of water in streaks throughout the central region of the log, as well as in the outer sapwood, with the result that such logs become especially liable to sinkage if left in water for prolonged periods. Logs of paper birch also showed a tendency toward a fairly uniform penetration of moisture throughout the central regions of the log, as well as in the outer layers.

The results indicated that, aside from the important consideration of density, logs with a large proportion of sapwood, or with permeable central regions, were most liable to loss by sinkage. Such material is found in small logs either from young trees, which are mostly sapwood, or from the tops of older trees. Trees with wide growth-rings may also be included among probable "sinkers", as fast growth tends to produce relatively wide sapwood. Logs with any considerable amounts of decay are especially liable to sinkage, since the decayed areas absorb water more readily than does sound wood.

As sound logs with comparable proportions of sapwood appeared to decrease in buoyancy at about

the same rates[13] the reduction of the weight per cubic foot of "sinker" stock by seasoning such logs prior to floating them appeared to be a logical method of retarding the ultimate loss of buoyancy. Reduction in the density of such stock by drying proved an effective method of prolonging the floating period over that for unseasoned stock (10), and the improvement in floating qualities seems definitely related to the reduction in density.

A summary of investigations on the sinkage of pulpwood, undertaken under the auspices of the Woodlands Section of the Canadian Pulp and Paper Association, was presented at the annual meeting of the Association in 1931 (26).

Relation of Permeability to Selection of Woods for Tight Cooperage

The use of wood in tight cooperage requires large amounts of high-grade material. Timber of the white oak group[14] is highly favoured for the manufacture of both staves and headings, since the presence of tyloses and thick-walled cells of such wood renders its heartwood practically impervious to liquids and endows it with strength and durability. Other woods, however, are about equally impervious to flow of liquids across the grain and should be satisfactory substitutes in other respects, especially in the manufacture of barrels that are coated inside with pitch.

[13] The measurement of buoyancy employed was the so-called "floating margin", which signifies the relative proportion of the volume of each floating log that projects above the water. The most accurate method of determining the floating margin of small numbers of logs is to determine the volume by displacement of water, and the weight of the log. Thus, when the weight per cubic foot is 47 pounds, the floating margin is about 25 per cent, and at more than 62.5 pounds per cubic foot (the weight of an equal volume of water), the log, of course, sinks. In measuring the floating margin of large numbers of logs it may be more convenient to calculate this value from the diameter of the log and its height above water-level.

[14] The white oak group is characterized by the possession of leaves with rounded lobes, in distinction to oaks of the red or black group which have leaves with pointed or bristle-tipped lobes. Heartwood of the white oaks is generally characterized by tyloses in the vessels. The wood is heavy, and except for the vessels has a large proportion of thick-walled cells, making it strong and relatively impervious to fluids under ordinary conditions.

The heartwood of the red or black oaks, as well as the sapwood, is generally characterized by large open vessels that render it easily permeable along the grain. Although of desirable weight and strength, it is naturally less suitable for tight cooperage than the impervious white oak, except for barrels that are given an internal liquid-proof coating.

SOME GENERAL PROPERTIES OF SAPWOOD AND HEARTWOOD

THE important properties of sapwood already mentioned in connection with the permeability of this type of timber require some further discussion. Some woods are characterized by thin sapwood, whereas in others the sapwood may be several inches in thickness. The width of sapwood, however, may be subject to considerable variation, even in the same kind of timber. The absence of colour in the tissues of the wood cells when first formed results in white wood; this wood, however, darkens with age. In many species, the darkening takes place quite abruptly, so that there is a distinct line of demarcation between the dark heartwood and the light-coloured sapwood.

The number of annual layers in sapwood of different trees of the same species may vary, as there is, apparently, no definite length of time required for the sapwood to change into heartwood. The time of the transition appears to be governed partly by the period elapsing after the wood is formed, and partly by the distance that separates the wood from the periphery of the tree. Thus, wood with wide growth-rings is likely to change into heartwood a little sooner than wood with very narrow growth-rings. In the test material observed at the Laboratories, the trees with wide rings produced, generally, wider sapwood than trees of slow growth, although the number of annual layers in the sapwood of the slow-growing trees may be much greater.

An example of specific differences in thickness of sapwood and the effects of rate of growth in two woods of somewhat similar appearance is shown in records of the examination of pole material of jack pine and red pine of comparable size. The wood of jack pine (*Pinus Banksiana* Lamb.) is distinguished from that of red pine (*P. resinosa* Ait.) by the wide sapwood of the latter. It will be noted from Figure 7 that sapwood of jack pine is usually less than two inches thick, the average thickness of sapwood in logs from nine to twelve inches in diameter measured in these observations being about 1½ inches. The average thickness of sapwood in red pine logs of similar diameters is slightly over three inches. Rapid growth tends toward the production of wide sapwood, and slow growth to the production of narrow sapwood.

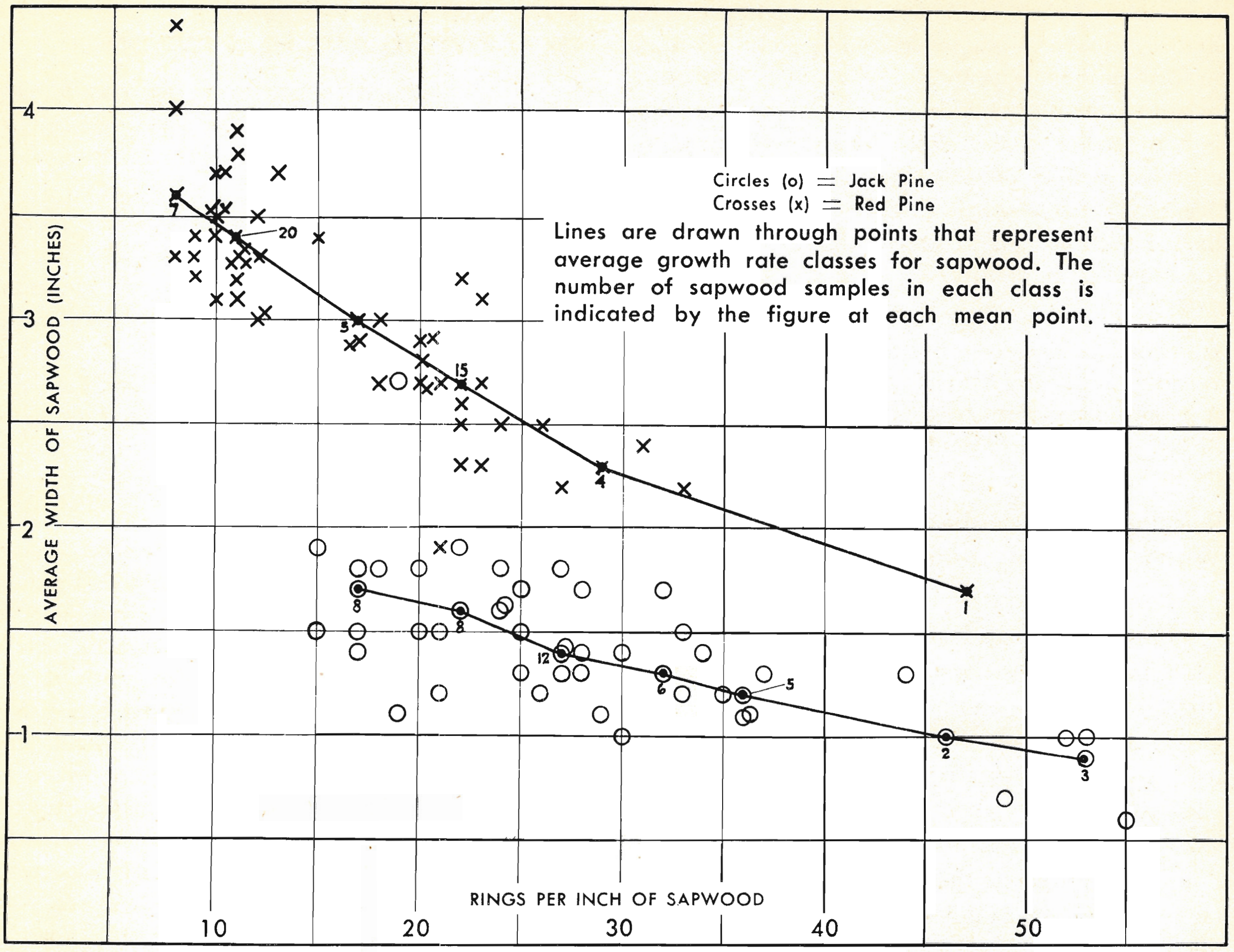


FIGURE 7.—Curves Showing Comparative Widths of Sapwood in Red and Jack Pine.

The darkening of heartwood may be due to chemical changes such as oxidation and the deposition of resin, gums, tannin, and other secretions. The heartwood of some species may have considerably greater density than the sapwood (11) because of the presence of such materials.

In softwoods characterized by the presence of resin canals, such as the pines, the freshly-felled sapwood contains oleoresin, which exudes in drying. The oleoresin is removed by kiln-drying in the case of lumber, or by chemical cooking if the wood is used for pulp. Such sapwood, therefore, is suitable for lumber or pulpwood, whereas the brown colour of the heartwood, due to resin, etc., makes the production of light-coloured pulp somewhat difficult. Therefore the young, fast-growing trees of species without much heartwood are the better suited for the manufacture of light-coloured paper (2).

In the case of lumber, however, heartwood is frequently preferred because of its greater resistance to decay and its freedom from certain stains that are primarily due to fungous action on the materials present in sapwood. Alternatively, for special uses where the question of decay resistance is not important, sapwood may be preferred for its light colour, straight grain, and freedom from defects.

FIGURE IN WOOD

THE subject of colour leads naturally to the ornamental aspects and the figure of woods. The figure may be due to the patterns formed by the growth-rings on the surface of boards or veneers. Typical growth-ring figures on quarter-sawn or plain surfaces are familiar because of the common use of wood with such natural designs in articles of furniture and interior finish (Plates 28, 31). The

contrast in texture and colour of spring-wood and summer-wood of such heavy softwoods as Douglas fir give the characteristic variegated pattern to plain-sawn material and to rotary veneer. Quartered material of such woods presents a growth-ring figure of parallel lines without so much variety as the plain-sawn wood. In woods such as oak, which have rays that are both broad and deep, the quartered surfaces show conspicuous stripes of varying width across the grain, which are formed by the exposed rays.

Other types of figure are due to variations in colour and grain. The wood of yellow birch sometimes shows a wavy grain, owing to the wave-like undulations which the wood elements follow. The light is reflected at varying angles from the surface of such wood, depending upon the inclination of the fibrous cells, so as to present a pleasing effect of alternating light and dark bands, which vary according to the direction from which the wood is observed. Undulating grain is often present in sugar maple in waves of shorter length and much closer spacing. In mahogany and other woods the effect of contrasting stripes is often produced by alternating zones of wood with the grain inclined at different angles. In some woods actual differences in colour in more or less irregular streaks present a pleasing type of figure.

A figured wood of interest among Canadian timbers is the so-called "bird's-eye" maple. The bird's-eye structure which occurs in hard maple (*Acer saccharum* Marsh.) is given to this wood by the presence of numerous radial series of conical depressions in the annual layers. Investigations carried out at the Laboratories indicate that these depressions are caused by the activity of parasitic fungi which are able to exist in the cambial tissue which generates the wood. The cambial layer, as previously noted, is located between the woody cylinder of the tree and the inner bark; from its inner surface it deposits the layers of wood on the tree, and from its outer surface, the bark. By local depletion of the cambium layer, the activity of the fungus prevents development of wood in certain areas, and though the cambium appears to recover shortly afterward, the region of greatest depletion is marked by a lack of wood or depression where the cambium was inactivated. The subsequent years' growths of wood become deposited on the depressions and conform to them, making long series of conical depressions, which, on the tangential surface of wood, show an approximately circular outline and cause pleasing variations in the grain. These markings may be variable in size (averaging about a tenth of an inch in diameter) and may be grouped as thickly as ten or more per square inch, producing a characteristic mottled effect.

Such series of depressions are found in many hardwoods, but, except in maple, very rarely occur in sufficient numbers to produce an ornamental effect. Radial series of depressions are also common in Sitka spruce, and are probably found occasionally in all softwoods. In the softwoods, the depressions are not usually conical, but may extend several inches along the grain.

CHARACTERISTICS THAT AFFECT FINISHING

THE figure of wood may be accentuated or softened by appropriate staining and finishing. Undulating grain, for example, is a common type of figure that may be accentuated by local penetration of coloured materials. In the parts of the "waves" where the grain (i.e., the direction of the tubular cells) intersects the surface of the wood, pigmented fillers or liquid stains may be applied so as to penetrate along the inclined cells comparatively deep below the surface. Where the "waves" turn, however, so that the grain is more or less parallel to the surface for a short distance, comparatively little penetration is possible and pigmented coatings or stains applied to the surface may be largely removed from these areas by rubbing. Such treatment accentuates the figure by darkening the undulations where the cells are inclined toward the finished surface. Usually, however, the ornamental effect of undulating grain—for example, fiddle-back, "quilted" figure, etc.—is adequately shown finished "natural" or with translucent stains and fillers to give a uniform colour.

Where lumber from softwoods with resin ducts is designated for interior use, proper drying is most important. In sapwood particularly, the fluid oleoresins tend to be drawn to the surface by heat, and instances where such exudations have softened or even penetrated the film of paint or varnish are very frequent. The heat applied in kiln-drying brings practically all the oleoresin to the surface, where the volatile constituents evaporate, leaving a coating of resin which is removed by the subsequent surfacing.

PLATE 40.—Cross-section of Softwood with Coating of Clear Finish (× 70).

PLATE 41.—Softwood Resin Penetrating Finish (× 70).

In some instances, coniferous species characterized by resin ducts (particularly the pines) may have resinous heartwood. In such 'pitchy' material, the resin is typically diffused throughout the wood, and is not confined to the inter-cellular ducts. Extremely resinous wood is, of course, easily recognizable. It presents a problem to painters, as the resin mingles with and often penetrates the ordinary linseed oil-turpentine paints, and in time turns them dark brown. The painting of knotty wood of such species may, therefore, demand that some form of sealing coat be applied to the knots in order to prevent the subsequent exudation of resin into the paint coatings, as the resin, which (like other fluid contents of wood) moves most easily in the direction of the grain, passes readily toward the cut ends of the knots, where it can discolour the paint. Plate 41 illustrates a defect caused by applying a finish coating to wood insufficiently seasoned. Fluid resin penetrated the finish locally, collecting dust particles that spotted the surface. While some resin canals extend radially, thereby permitting some flow of liquid resin across the grain, the principal canals run parallel to the grain. Shellac, the sealer most commonly used, is effective for a time only, and will ultimately allow resin to penetrate and darken light-coloured paints. An effective sealing coat for such knots should be impervious to turpentine.

Woods ordinarily take paint readily, with the exception of abnormally resinous timber. In interior work, there should be little difficulty regarding the life of paint coatings, since such wood is not subject to the extremely wide variation of conditions that obtains outdoors. Moreover, interior woodwork is generally dried to a proper moisture content before painting or enamelling and generally has little opportunity to alter greatly in moisture content during its subsequent period of use. The appropriate employment of fillers, therefore, permits even the woods with large pores to be painted satisfactorily.

Outdoor woodwork, however, is subject to rain, cold, and heat, and it is significant that the woods on which paint lasts longest are those characterized by relatively uniform structure and the minimum of dimensional changes due to variations in moisture content. Among the best from the standpoint of long life of paint-coatings are the cedars (6), which are characterized by smaller shrinkage factors than other

woods. Paint coatings are not fully impervious to water vapour, so that the wood beneath is still subject to some expansion and contraction with periods of wet and dry weather. The cumulative effect of alternating dimensional changes tends to loosen the paint film, which has a coefficient of expansion that differs from that of wood. It has been found that paint coatings generally are retained longest on quarter-sawn boards, but have a comparatively short life on flat-sawn stock, particularly on summer-wood. It has been shown previously that the changes in width of boards are greatest in flat-sawn material. Further, such dimensional changes as take place are bound to be at the maximum in the dense summer-wood which frequently offers a less effective bond to paint coatings than is presented by the spring-wood.

CHARACTERISTICS OF IMPORTANCE IN PULP AND PAPER MANUFACTURE

IN manufacturing paper from wood, the latter is reduced to pulp either by chemical action which removes the cementing substance that holds the walls of neighbouring cells together, or by grinding the wood on revolving stones (Plates 42 and 43). Paper is made by depositing an even layer of dilute water-suspension of pulp on a fine screen that permits the water to drain through but retains the layer of wood fibres. The layer of fibres, removed from the screen and finally pressed and dried, becomes a sheet of paper, the characteristic qualities of which depend basically on the colour, dimensions, flexibility, strength, and other related properties of the fibres.

The use of woods with long fibres tends to make

PLATE 42.—Fibres of Sulphate Pulp (× 120).

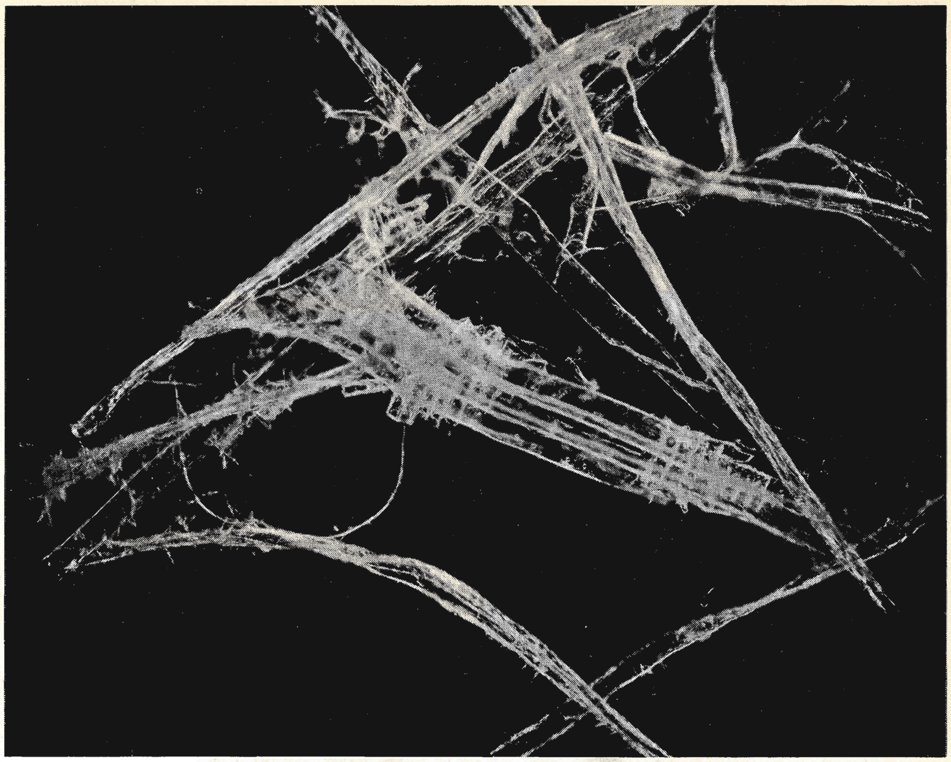


PLATE 43.—Fibres of Groundwood Pulp (× 100).

a strong sheet, because a considerable length of fibres permits more intertwining and "felting" action than is possible with short ones. However, for a sheet without unduly large gaps between the fibres it is necessary that a considerable proportion should be short so as to fill interstices that otherwise would be left in the network of long fibres (8).

Spruce has, for a long time, set the standard as a desirable pulpwood because of its lack of colour, its long fine fibres (tracheids), its abundance, its adaptability to pulping processes, and its basic density, which ensures a satisfactory yield of pulp per unit of volume.

While the average length of the fibres of Eastern Canadian spruce is about an eighth of an inch, it is not the same everywhere in the tree. Those fibres that are formed when the tree is very young and small are relatively short, and in wood close to the pith are of smaller diameter than the fibres formed when the tree is mature. Studies of the variations in length of fibres made by Lee at the Laboratories indicate that each successive year the fibres formed by softwoods are generally longer than the fibres of previous growth until, after some fifty years, fibres of about maximum length are produced, and the fibres formed subsequently show comparatively little variation from this length. Lee also reports some difference in the maximum fibre length, depending on the height in the tree, and finds the longest fibres occur about 16 feet above the ground level (29).

The following diagram is based on figures giving the length of fibres found in white spruce, *Picea glauca* (Moench) Voss, at various distances from the centre of the log; these figures are averages from trees of various growth-rates sampled at the Laboratories. Measurements of fibres from the butts to the tops were combined to arrive at these average figures.

The softwoods of Eastern Canada all have fibres of about the same length as those of the eastern spruces. Softwood species of the extreme west (for example Sitka spruce, Douglas fir, western hemlock, and western cedar) have considerably longer fibres than the eastern species. These species exhibit variations in the length of fibres that follow the same general pattern indicated for the softwoods in general. The average length of fibres in hardwoods is short, being generally less than half that of fibres of eastern spruce.

The demand for paper and other pulp products has brought increased use of a wide variety of pulpwood species. The advantage of using heavier pulpwoods, such as certain available hardwoods, capable

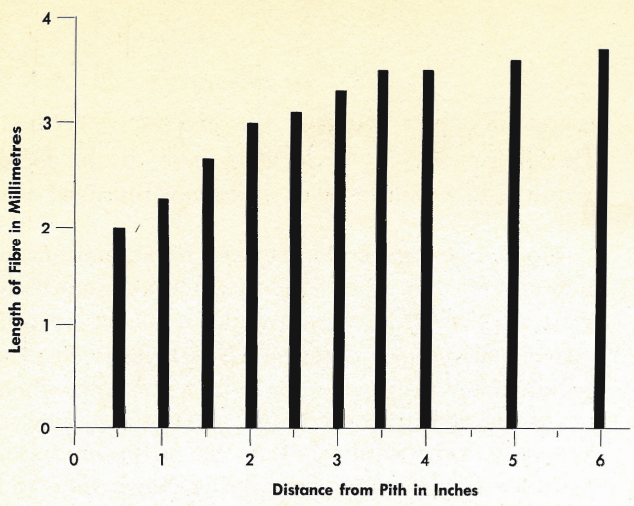


FIGURE 8.—Relative Lengths of Spruce Fibres.

of producing more pulp per unit volume of wood than the softwood pulpwoods is obvious, so that pulping of hardwoods has greatly increased during recent years.

CHARACTERISTICS OF IMPORTANCE IN BENTWOOD

THE elastic properties of wood permit it to be bent to curved shapes. If wood is properly softened by heating in moist condition, it can be bent into curves which the wood will retain after cooling and drying, and which would be impossible with untreated wood.

The first stage in the process of making bends with solid wood is to soften the selected stock by moist heat in preparation for bending. This is followed immediately by bending the softened wood while hot. The drying of bent pieces so that the material may retain its bent shape is the last stage of the operation before final processes of manufacture and finishing.

Wood may be softened for bending by boiling, or by steaming it either in a chamber at atmospheric pressure or in special retorts where higher pressures may be employed. High pressures are not required, however, since wood may be rendered sufficiently pliable by raising its temperature to about that of the boiling point of water, provided the wood contains enough moisture initially. In general, about 45 minutes of boiling or steaming at atmospheric pressure per inch of thickness seems to be required to raise the temperature of wood so as to condition it for bending. It is reported that handles of walking sticks are rendered plastic for bending by heating in wet sand (37, 41).

It has been found that certain chemicals make wood pliable, and in recent years patents have been issued for processes for softening wood with urea and with certain tanning agents. Green wood is used for the urea treatment and is soaked in a 50 per cent solution until it has absorbed an amount of urea equal to a quarter of the oven-dry weight of the wood. Wood so treated requires careful seasoning at temperatures below 140°F., after which it become pliable on the application of heat. The bent wood becomes firmly set on cooling if the wood was dried to the recommended moisture content of 8 to 12 per cent before bending. Re-softening of wood bent by this process may be prevented by adding formaldehyde or certain other chemicals to the urea bath and heating the bent stock to temperatures upwards of 300°F. Patents for these urea bending processes are held by the United States Department of Agriculture. Other chemical bending methods are said to render wood pliable in its wet condition, so that it may be easily bent after soaking, retaining the new shape and its natural elasticity on drying (40).

Chemical methods of softening wood do not seem to be very widely used. It does not appear that they offer any clear advantages over the steaming and boiling process, while on the other hand certain disadvantages are very obvious: processes using urea or tanning agents darken the wood, while the urea-formaldehyde process tends to bleach it; the urea treatment, moreover, tends to leave the wood somewhat moister than untreated wood.

In making bends of gradual curvature*, the softened blanks may be clamped between male and female forms, or may be forced tightly against a form shaped to the curvature required. In sharp bends, where the outside of the blank would undergo a perceptible degree of stretching while the inside, in contact with the form, is being compressed, the wood is given special protection to prevent the stretched area from pulling apart in failures from tension. Flexible metal liner straps are used on the convex surface of sharp bends to ensure that most of the deformation undergone during bending shall be forced to take place as compression, since a considerable amount of compression along the grain may be induced without visible breakage, whereas

*Gradual curvatures for wood with good bending properties may be defined as those in which the ratio between the thickness of the wood and the radius of curvature is not more than 1/40.

wood can be stretched only about one per cent of its length without failure (41) (Plate 44). In the usual bends, therefore, where the pieces of wood are bent away from the direction of the grain (actually bending the fibres in the process as in handles, chair-posts, toboggan slats, etc.), the individual wood cells at the inside (concave) surface of the bend accommodate to the compression along the grain by more or less telescoping, with the formation of typical slip-lines, indicating microscopic compression-fractures (Plate 39).

Where accuracy of shape is essential, bentwood is supported in its bent position until dried to the approximate moisture content required in its use, since such bent stock tends to straighten with absorption of moisture, whereas loss of moisture causes it to bend somewhat more.

Various factors are important in the selection of wood for bending. The ring-porous woods, such as ash, elm, oak, or even hickory (which tend toward a diffuse-porous type of structure), are among the species considered most satisfactory for bending into permanent curved shapes, although most of the common hardwood species of Canada are used in bentwood products. Hardwoods generally bend better than softwoods.

Wood selected for bending should be sound, straight-grained, and free from defects. Knots, checks, worm-holes, and even slight irregularities of structure in key positions may cause the wood to break during the process of bending. Wood showing fungous stain or streak is therefore rejected, as is material of abnormally light weight, also other types of weak or brash wood liable to abrupt breaks across the grain.

Stock for bentwood may be either green or air-dry, if free from seasoning checks or other significant defects. Air-seasoned wood is generally preferred, since the bent stock can be more quickly and easily dried than green material.

SOME GENERAL EFFECTS OF NAILS ON WOOD

NAILS are the commonest form of fastening used in wood construction. Various factors affect the holding-power of nails in wood, notably the density of the wood, the diameter of the nail, the depth to which the nail is driven, the angle of the nail in relation to the grain, and the particular way in which the nail has distorted and broken the surrounding wood during the process of driving. (Holding-power, as understood here, is the force required to withdraw or to start the withdrawal of a nail.)

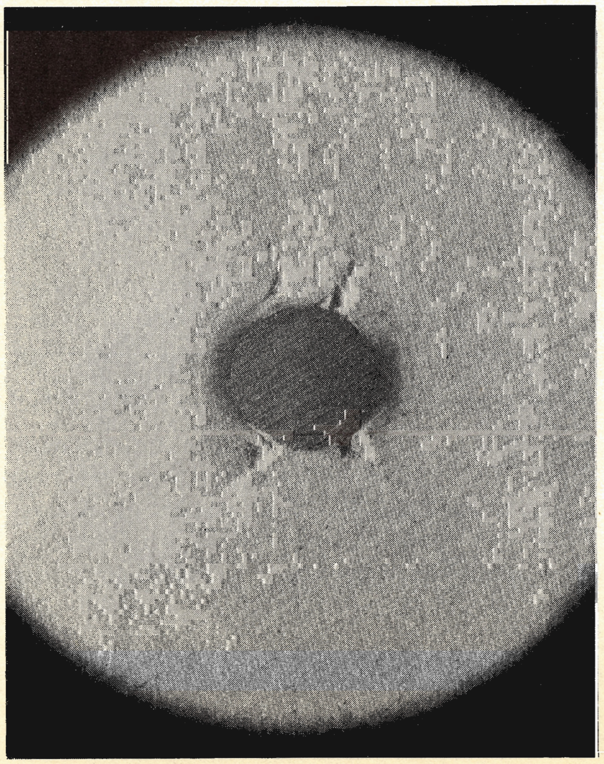
More force is generally required to pull nails from dense wood than from light-weight wood, and nails generally show the most resistance to withdrawal (particularly in the softer woods) when driven perpendicular to the grain, and the least resistance when driven parallel with the grain. The holding-power generally varies with the diameter of the nail also, provided that the nail is not so big that it splits the wood (see Chapter 13).

PLATE 44.—Failures in Steam Bending.

It has been found that holding-power of nails may decrease significantly if the moisture content of the wood changes appreciably after the nails have been driven, whether the wood is green and loses moisture or is dry and becomes moist again after nailing. Careful examination of nails *in situ* shows that this apparently contradictory situation is explained by the distortion caused by the nail in the wood surrounding it. Tests where common wire nails were driven radially into air-dry red pine may be cited to illustrate the reason for this loss in holding-power.

The magnified illustrations (Plates 45 and 46) show that the point of the common wire nail displaces the wood so as to cause considerable compression of the wood fibres across the grain. For purposes of illustration, the parts of the nail that effect such compression of wood at right angles to the grain are here designated as the "sides" of the nail (even though wire nails are circular in cross-section). A line through the points of compression perpendicular to the grain, therefore, passes through the sides, so that the "top" and "bottom" of the nail's cross-section would be points on another line perpendicular to the first one. The second line, of course, would be parallel with the grain.

The action of common wire nails driven into wood, aside from possible cutting effects of the nail-point, is to displace and divide the wood on opposite sides of the point and thus compress wood across the grain about equally to the right and left of the nail. Such lateral displacement, forcing the wood fibres out of the normal straight alignment and curving them around the circular cross-section of the nail, is usually sufficient to stretch the distorted fibres beyond their elastic limit and so to cause the wood to break across the grain on both sides of the nail at the top and bottom. This is illustrated in Plate 45 which shows, at low magnification, paired breaks near both the top and bottom of a nail driven radially into air-seasoned red pine. Because the movement of the nail as it penetrates causes displaced fragments to bend in the direction of the nail's travel, it seems evident that forces other than those of simple tension along the grain and compression across the grain are involved in the displacement of wood by nails. However, the paired breaks at top and bottom of the nail,



PLATES 45 & 46.—Breaks in Wood Fibres Caused by Common Wire Nail (× 5).

and the compressed fibres to the right and left, form a typical pattern of disrupted structure that generally accompanies the penetration of common nails with the usual "diamond" point.

Examination of the displacement of wood along the length of a common nail (Plate 46) shows how the broken pieces of wood incline more or less sharply from the direction of the grain toward the direction in which the nail is driven. This completed picture of the action of common nails is sufficient to explain the loss in holding-power with changes in moisture content. The fact that nails in seasoned wood lose holding-power when the wood becomes wet may be explained in great part by the enlargement of the nail-hole that accompanies significant swelling of wood as it absorbs moisture. Similar loss in holding-power because of the drying of wood is associated with shrinkage across the grain of the broken wood which lines the nail-hole at the top and bottom. Such fragments of wood, being inclined across the grain, contribute a cross-grain shrinkage component in drying that causes the wood to draw away from the top and bottom of the nail, increasing the diameter of the hole vertically, and so causing the wood to loosen its hold in that dimension, even though shrinkage along the grain of normal wood may be insignificant.

The type of point has considerable effect on the amount of distortion that nails cause in the wood structure. Nails with blunt, square-edged points are commonly employed in woods liable to split. Such points cut or tear by impact a large hole, thereby reducing the tendency to lateral compression of wood across the grain and minimizing splitting, although the holding-power is generally reduced by the disruption of the wood.

A common nail with its original diamond point ground to a sharp wedge will produce either a splitting or a cutting effect, according to the relation of the cutting edge to the grain. Driven radially, with the sharp edge squarely across the grain, the fibres are cleanly cut and turned fairly uniformly towards the direction of drive, with a minimum of irregular breaks or torn fragments; driven with the wedge point parallel with the fibres, there is practically no cutting action, the nail simply forcing aside the wood in its path, with the consequence that holding-power is greatly lessened.

Nails with particular types of point, surface, coating, or configuration, all having some special advantage, have been developed; for particular information on this subject, see Chapter 13.

CONDUCTIVITY

Thermal Conductivity

WOOD is of value for its insulating effect in house construction, since, as compared to most other common structural materials, it does not conduct heat readily. Wooden houses, if properly constructed, may, therefore, be economically heated in cold weather, and maintained relatively cool during hot weather.

The thermal conductivity of wood is directly related to its density, the heaviest woods having the least insulating effect. This situation arises from the cellular nature of wood, the lightest woods being those that contain the greatest proportion of closed air-spaces in relation to the solid substance of the cell walls. The thermal conductivity of wood is expressed as the amount of heat in British Thermal Units transmitted in one hour through one square foot of homogeneous material, one inch thick, for a difference in temperature of one degree Fahrenheit between opposite surfaces. Thermal conductivity is measured across the grain of wood, since in sheathing and partitions this is the general direction of the flow of heat.

Tests (36) have indicated the relationship between the thermal conductivity and the density of seasoned wood. While some of the species reported show individual variations in behaviour, it will frequently be of value for practical purposes to compute the average thermal conductivity of dry wood from the density. Thus, when the density of a wood is known, its thermal conductivity (K) at 12 per cent moisture content may be approximately calculated from the equation $K = \frac{W+5}{43}$ where W is the weight in pounds per cubic foot of the wood at 12 per cent moisture content (the average deviation from this equation is 6 to 7 per cent in the twenty-two species noted). As the presence of water in the wood affects the conductivity, material that is kiln-dried to moistures less than 12 per cent will have lower conductivity, whereas material containing more than 12 per cent moisture will conduct heat more readily. An allowance of approximately 0.007 B.T.U. is required for each one per cent difference from the 12 per cent moisture content.

Some of the building boards and insulation boards used in house construction are manufactured from wood and other fibrous materials that have been reduced to a pulp. Such wood-fibre boards are generally lighter in weight than the common woods, ranging from about thirteen pounds per cubic foot upward. The insulating value of the most effective of such materials* in ordinary commercial thickness of one-half inch is reported to be about equivalent to a full inch thickness of the ordinary light-weight woods such as spruce, balsam fir, and white pine.

The time-honoured practice of employing a fill of sawdust or shavings in the spaces of wall and ceiling construction, as thermal insulation of buildings, has provided records of service for these materials that are probably not yet equalled by newer types of insulation. In some cities, however, building regulations are interpreted as preventing the use of sawdust or shavings for thermal insulation unless the materials have been treated so as to be fire-resistant.

It is of interest in this connection to note that instances have been commonly reported where frame walls filled with sawdust or packed shavings withstood fires better than hollow walls, since the fill of small particles so effectively prevented circulation of air as to prevent or retard burning, whereas hollow walls frequently act as flues and help to spread the flames. So far, therefore, from a fill of dry sawdust or well-packed shavings constituting an additional hazard in frame construction, it seems probable that such a procedure, by providing an effective fire-stop, actually lessens the fire hazard while at the same time giving excellent insulation.

In using sawdust for insulation, it is recommended that the material should be used in reasonably dry condition, and should be compacted by light tamping, to prevent subsequent settlement. It is not feasible to compress sawdust significantly when it is used as loose fill in partitions. In like circumstances, however, shavings are capable of considerable compression, and should be tamped down manually so as to ensure the elimination of air pockets. Tests indicate that, unlike sawdust, the thermal insulating value of planer shavings improves with compression, so long as such compression is only manual†.

*Thermal conductivities suggested for use in computing the relative insulating effect of a wide variety of materials are listed in the annual "Guides" of the American Society of Heating and Ventilating Engineers.

†Unpublished report by Professor E. A. Allcut, University of Toronto.

Widely available materials such as sawdust or shavings ordinarily provide the most inexpensive, and one of the most effective, forms of thermal insulation when applied as fill in hollow walls, values for thermal conductivity as low as one-third of a B.T.U. per hour having been reported.

Those who make use of loose wood-fibre thermal insulation as an economical practice in modern housing should be familiar with proper methods for its application, in order to ensure that it will not be exposed to sources of extreme heat, such as flues, chutes, heating pipes, etc., and that the heating conduits and wiring, as well as the general construction, conform to acceptable standards. The current Canadian Electrical Code (Rule 205C) requires that thermal insulation which will be in contact with electric wiring shall be non-corrosive, non-conducting, and fire-resisting, and that the insulation shall be applied in such a manner as not to place any strain upon the electric installation. It provides further, where the insulation material is combustible, that electrical conductors shall run in suitably sealed rigid metallic conduits, or in flexible conduits with approved protection.

While some mixture of fire-retardant chemicals may be combined with sawdust or shavings, it is evident that this defeats the purpose of providing inexpensive insulation. The service records of these materials have been established without the aid of chemical admixtures and since the addition of foreign substances may render the insulation "corrosive" or "conductive" within the meaning of the Electrical Code, the usefulness of chemical treatment for sawdust or shavings used for insulation seems questionable.

Electrical Conductivity

Oven-dry wood is, for practical purposes, a non-conductor of electricity. In ordinary use, however, small amounts of moisture are always present, and these make possible the passage of feeble electrical currents. Advantage of this circumstance has been taken to produce a device which measures instantaneously the moisture content of seasoned wood by determining the resistance to an electrical current passed through it. The device is effective over a range of from 7 to 24 per cent moisture content, within which range resistance across the grain, is slightly greater than logitudinally.

KEY TO THE IDENTIFICATION OF WOODS COMMONLY USED IN CANADA

Examination of smoothly cut end-grain surface of wood shows that

I. Numerous pores are visible with or without the aid of magnification.

A Pores are scattered more or less uniformly throughout the annual ring. In this case the sample is a Diffuse-Porous Hardwood and must be identified according to the key for such woods.

B Pores are noticeably larger in the spring-wood than elsewhere, and the larger pores, close together, form a more or less continuous row on the inside of the annual ring. In this case the wood is a Ring-Porous Hardwood and must be identified in accordance with the key for identification of ring-porous hardwoods.

II. Pores are absent and the general cell structure of the wood is visible only with magnification. In this case, the sample is a Softwood and must be identified according to the key for softwoods.

Softwoods

I. Resin ducts present more or less uniformly throughout—

A Resin ducts large, relatively distinct, and numerous. (Resin ducts visible as light-coloured or dark spots on end-grain. On tangential surfaces of boards, resin ducts are plainly visible as fine longitudinal lines or scratches.)

(1) Summer-wood inconspicuous. Wood practically uniform and very easy to carve across grain THE WHITE OR SOFT PINES

(2) Summer-wood conspicuous, darker and harder than spring-wood, from which the transition is more or less abrupt .... THE HARD PINES

B Resin ducts small, relatively inconspicuous, usually not numerous.

(1) Summer-wood not very conspicuous, transition from spring-wood gradual, wood moderately light in weight. Colour creamy white to light yellowish-brown .... THE SPRUCES

(2) Summer-wood conspicuous, darker and harder than spring-wood, from which the transition is more or less abrupt.

(*a*) Heartwood light russet-brown with grey tinge .... THE LARCHES

(*b*) Heartwood light reddish-brown .... DOUGLAS FIR

II. Resin ducts normally absent, or if present occurring locally in tangential rows in only a few isolated annual rings (in hemlock and the true firs), often associated with a wound in the tree.

A Wood does not appear resinous or waxy.

(1) Wood without pronounced spicy, aromatic, or pungent odour.

(*a*) Transition gradual from the spring-wood to the thin summer-wood, which is scanty and rather soft. Spring-wood nearly white, with the darker summer-wood sometimes light to dark brown THE TRUE FIRS (Genus *Abies*)

(*b*) Transition from spring-wood to summer-wood may be more or less abrupt. Wood with a pale reddish-brown tinge and, when fresh, with a faint sour odour .... THE HEMLOCKS

(2) Wood with spicy, aromatic, or pungent odour.

(*a*) Heartwood reddish-brown .... WESTERN RED CEDAR

(*b*) Heartwood yellowish-brown .... EASTERN CEDAR

(*c*) Heartwood creamy or sulphur-yellow .... YELLOW CEDAR

B Wood waxy in appearance and to the touch on longitudinal surfaces. Colour variable from light-brownish to reddish-brown, sometimes blackened. Growth-rings often irregular in width. Summer-wood variable. Odour somewhat rancid .... SOUTHERN CYPRESS

Hardwoods, Ring-Porous

I. Many rays very broad and conspicuous without the aid of a lens; often as broad as, or broader than, the large pores in the spring-wood. Summer-wood often figured with wavy or branched radial bands...... THE OAK GROUP

A Small pores of the summer-wood too fine and numerous to distinguish easily with a lens. Large pores of spring-wood filled with tyloses in heartwood.................................. THE WHITE OAKS

B Small pores of the summer-wood larger and less numerous than in white oaks, distinctly visible with lens. Large pores of spring-wood mostly open and free from tyloses.................. THE RED OAKS

II. All rays definitely narrower than large pores of spring-wood. Rays in some woods visible without lens, in others very fine and not distinct without lens.

A Summer-wood figured with wavy or branching radial bands visible without lens. All rays very fine.... CHESTNUT

B Summer-wood figured with long or short tangential bands or lines, which may be wavy. Bands visible without lens.

(1) Lens shows bands to be composed of numerous pores joined in wavy line............. THE ELMS

(*a*) Large spring pores usually in one row except in very wide rings.

(i) Spring pores conspicuous because close together and large enough to be distinct without the aid of a lens.. WHITE ELM

(ii) Spring pores inconspicuous because small; often barely visible without the aid of a lens and somewhat separated. (Largest pores sometimes separated laterally by a space 5 or 6 times the pore diameter.) Bands of fibrous wood between the bands of pores usually wider than in white elm. Wood generally heavier and harder than white elm.. ROCK ELM

(*b*) Large spring pores in several rows............................ RED OR SLIPPERY ELM

(2) Lens shows bands to be composed of light-coloured tissue (parenchyma) surrounding the few smallest pores in outer portion of summer-wood and projecting tangentially, often so as to join pores widely separated. Pores of summer-wood few and isolated or sometimes in radial rows of usually 2 or 3.. WHITE ASH OR GREEN ASH

[As the tangential bands in Canadian Ash are sometimes not sufficiently prominent to be visible without a lens see also next section (C).]

C Summer-wood figured with long or short tangential bands or lines visible with the aid of a lens. Pores in summer-wood comparatively few and isolated or adjacent radially in groups of usually two or three.

(1) Projections of light-coloured tissue (parenchyma) extending from around pores in tangential direction visible with lens. Tangential bands of parenchyma may sometimes connect pores widely separated... WHITE ASH, GREEN ASH

(2) Light-coloured tissue (parenchyma) in numerous fine tangential lines plainly visible with lens, throughout summer-wood... THE HICKORIES

D No lines of light-coloured tissue (parenchyma) visible except sometimes short projections from outermost pores of summer-wood.. BLACK ASH

Hardwoods, Diffuse-Porous

I. Pores invisible or barely distinguishable without the aid of a lens.

A Some of the rays wide (twice the width of the largest pores or even wider).

(1) Wide rays numerous, usually not over an eighth of an inch in depth (along the grain), but very rarely a quarter of an inch, distinctly visible on smooth tangential surfaces without the aid of a lens. On radial surfaces rays form distinct brownish "flakes". Pores in final bands of summer-wood very fine or absent... BEECH

(2) Wide rays not numerous, often over an inch apart and often more than an inch in depth. Distinctly visible without the aid of a lens on smooth longitudinal surfaces. . . . . RED ALDER

B Widest rays about as wide as, or slightly wider than, the largest pores.

(1) Pores not crowded, diffused fairly uniformly throughout annual layer singly or occasionally grouped in radial series of, usually, 2 to 4. Rays on radial surfaces form conspicuous flakes of darker brown colour than the rest of the wood. Annual layers distinguished by rather definite brown lines, easily seen on radial surface. . . . . SUGAR MAPLE

(2) Pores generally most numerous in spring-wood. Pores rarely show a general tendency toward grouping in more or less loosely defined wavy tangential bands. Rays distinct, often lighter than the rest of the wood when seen on radial surfaces. . . . . BLACK CHERRY

C Widest rays narrower than largest pores.

(1) Pores comparatively large as seen under lens (about 0.1 millimetre in diameter).

(*a*) Rays sufficiently wide to be distinct under lens. (If surrounding wood is of the same colour as the rays, careful examination may be required to distinguish the rays without the aid of the lens.)

(i) Pores not crowded but distributed uniformly singly, or sometimes grouped, in radial series of mostly 2 to 4. . . . . THE BIRCHES

(*b*) Rays very fine, not distinct without the aid of a lens.

(i) Pores numerous, sometimes rather crowded. Wood greyish white to creamy brown with greyish tinge. . . . . COTTONWOOD AND OTHER SPECIES OF POPLAR (POPULUS)

(2) Pores comparatively small.

(*a*) Rays barely visible without the aid of a lens.

(i) Pores not crowded but distributed uniformly, singly or in radial series of mostly 2 to 4, wood light-brownish in colour. . . . . THE SOFT MAPLES

(ii) Pores numerous or crowded locally.

(*2a*) Heartwood varying from very light brown to darker shades with yellowish-green tinge. . . . . TULIP (YELLOW POPLAR)

(*2b*) Heartwood light creamy-brown. . . . . BASSWOOD

(*b*) Rays fine, not clearly distinguishable without the aid of a lens.

(i) Pores uniformly crowded throughout most of annual layers. Colour of heartwood reddish-brown, sometimes with olive or greyish tinge. . . . . RED GUM

II. Pores easily visible on all surfaces without lens and on longitudinal surfaces appearing as numerous minute grooves or scratches.

A Annual layers distinctly defined throughout.

(1) Colour of wood chocolate-brown. Pores sometimes tending toward "ring-porous" arrangement BLACK WALNUT

(2) Colour of wood reddish-brown, varying from light to dark shades. Pores distributed uniformly, may contain brown gum or white deposits. Tangential surface often shows ripple marks due to the arrangement of the rays in tiers. . . . . AMERICAN MAHOGANY

B Annual layers indistinguishable, although vague light-coloured streaks extending several inches may be noticeable locally on end-grain surfaces.

(1) Ducts (like resin ducts of softwoods) present containing a whitish gum. (Owing to the arrangement of the ducts in tangential lines, the bands of ducts may be mistaken for the limits of annual layers until examined with a lens). Pores very coarse, in colour russet to dark brown, sometimes with reddish tinge. . . . . PHILIPPINE MAHOGANY

(2) Ducts absent or inconspicuous, sometimes arranged in tangential lines containing brown gum. Colour of wood reddish-brown. Pores may contain brown gum . . . . AFRICAN MAHOGANY

The botanical names of species mentioned in the above key which are not indigenous to Canada are as follows:—

Southern Cypress, *Taxodium distichum;* American Mahogany, *Swietenia* spp.; African Mahogany, *Khaya* spp.; Philippine Mahogany, *Shorea* spp.

NOTE.—*In cases where the accurate identification of wood is important, the Laboratories will undertake to perform this service on receipt of a small sample of the material in question.*

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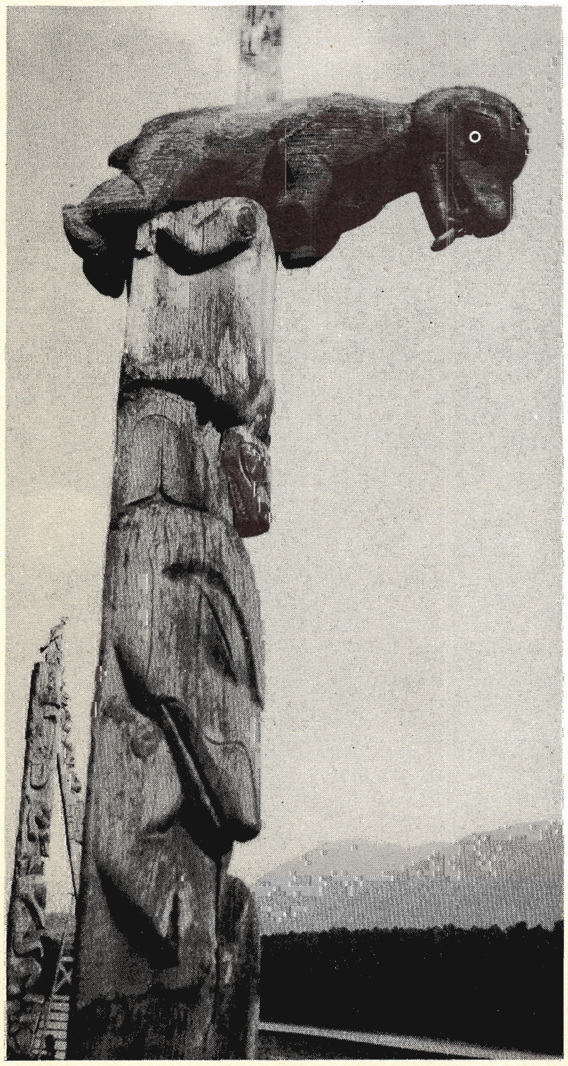
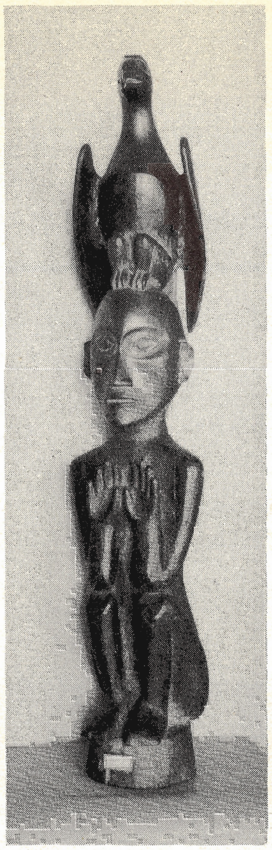
Interior of Salish Indian House

1





3

1. Haida Medicine Man Mask.
2. Wolf and Mountain Lion on Totem Pole.
3. Carving from Grave of an Eagle Chief.
4. Totem Pole, Kitwanga.

2

4

West Coast Indian Carvings

THE MECHANICAL AND PHYSICAL PROPERTIES OF CANADIAN WOODS IN RELATION TO THEIR USES

by W. E. WAKEFIELD*

IN THIS section it is intended to present data on the properties of Canadian woods which will serve as references for architects, engineers, and others interested in the use of wood as a structural material. Factors which affect the strength of wood are dealt with in the first part; and the strength of timbers, such as beams, poles, and ties, is discussed in the second part[1].

FACTORS AFFECTING THE STRENGTH OF WOOD

Specific Gravity

THE specific gravity of a substance may be defined in general terms as being the ratio of the weight of the substance to the weight of an equal volume of water. As has been explained elsewhere, wood fibre is composed of hollow, tube-like cells. The cell cavities contain, for the most part, air and water; the cell-walls are made up of the actual wood substance, which has, approximately, the same specific gravity without regard to species (27). Different species, however, have different growth characteristics, and such differences may even be found in the same species. As a result, the size and arrangement of the cells and the thickness of the cell-walls vary; hence the actual amount of wood substance in a given volume varies over a considerable range.

The term "specific gravity" is closely related to the term "density", since, if we refer to a wood of high specific-gravity value, we imply a wood of great density. In commercial practice, when a wood is referred to as being "dense", we refer to one having considerable weight in relation to its volume.

An analysis of the experimental data obtained from a great many specific-gravity tests shows a comparatively wide range of values for the specific gravity of the wood from the different species; and also for different specimens from the same species. In some instances, the presence of substances such as resins and oils has a marked influence on the specific gravity, but in most cases the differences in value are accounted for by the varying amounts of actual wood substance per unit volume in the specimens tested.

As might be expected, increases in the amount of wood substance per unit volume are accompanied by increases in strength. Figure 9 indicates the relation between specific gravity and maximum crushing strength parallel to the grain. In this instance, the relation varies as the first power of the specific gravity; in other strength relationships the stress may vary as some higher power of the specific gravity. However, when high specific gravity is due to substances within the cell cavities, such as resin, the above-indicated relationship does not hold, since the presence of these substances adds only to the specific gravity and not to the strength.

*In bringing this Chapter up to date, extensive use has been made of the original material prepared by Mr. G. H. Rochester for the first edition.

[1] For more specific data with regard to the strength of timbers used in construction the appendix should be consulted. These data are presented in tabulated form similar to that ordinarily adopted in engineering handbooks.

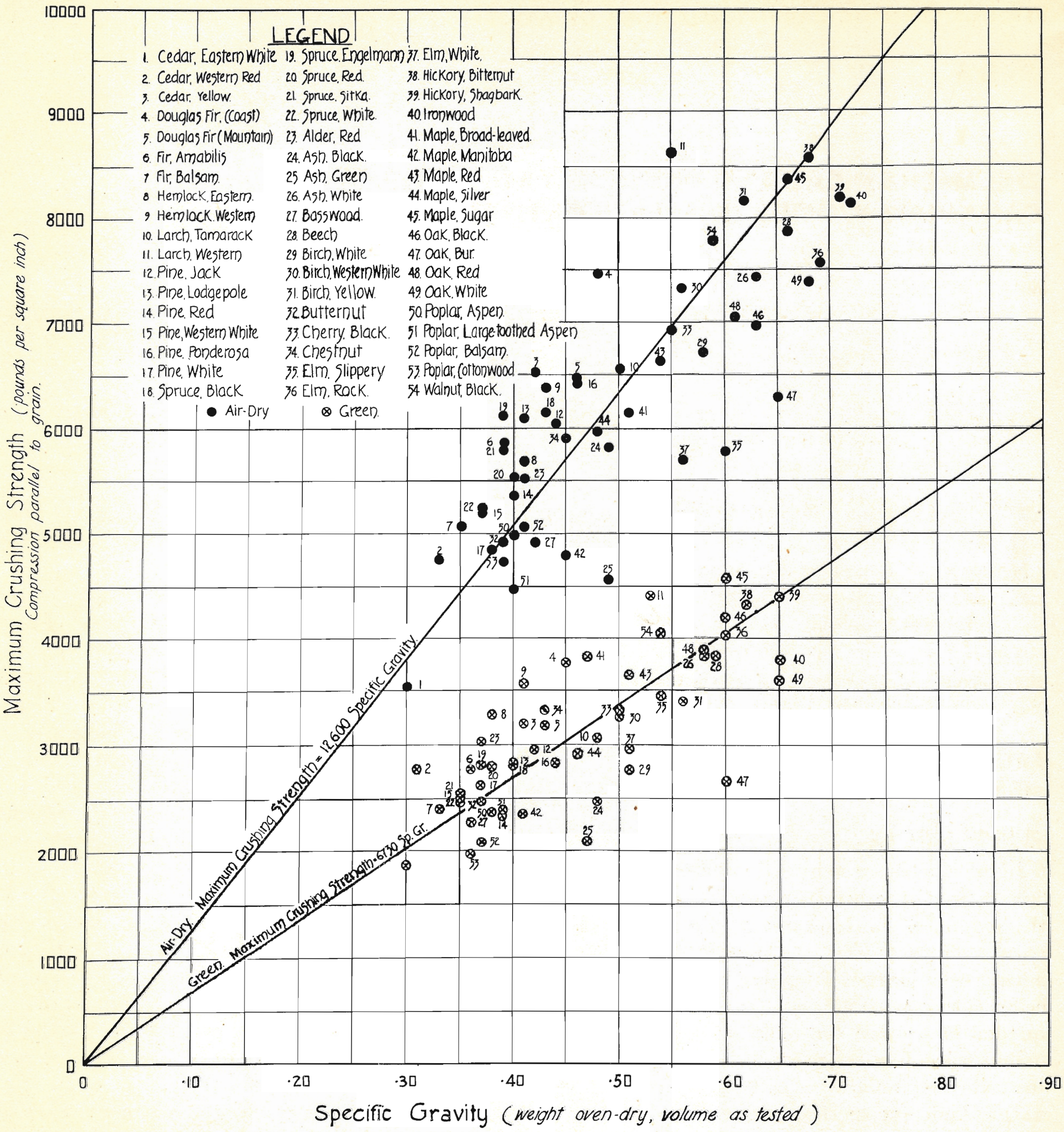


FIGURE 9.—Relation Between Maximum Crushing Strength and Density (average species values of woods grown in Canada)

Markwardt (22) has expressed the strength-specific gravity relations in the form of equations. When the equations and the average specific gravity of a species are known, an estimate of the strength of a species can be made. The equations shown in Table 8 will not give exact results for all species, as certain of these have special characteristics, which cause some variation between the estimated values and those obtained by tests. In general, however, the values obtained by this method of estimation are approximately correct.

The equations cited, while useful for the estima-

STRENGTH-SPECIFIC GRAVITY RELATIONS OF WOOD*

TABLE 8

PROPERTY	UNIT	MOISTURE CONDITION: Green	MOISTURE CONDITION: Air-dry (12% Moisture Content)
STATIC BENDING			
Fibre stress at P.L.	Pounds per square inch	$10{,}200G^{1.25}$	$16{,}700G^{1.25}$
Modulus of rupture	Pounds per square inch	$17{,}600G^{1.25}$	$25{,}700G^{1.25}$
Modulus of elasticity	1,000 pounds per square inch	2,360G	2,800G
IMPACT BENDING			
Fibre stress at P.L.	Pounds per square inch	$23{,}700G^{1.25}$	$31{,}200G^{1.25}$
Modulus of elasticity	1,000 pounds per square inch	2,940G	3,380G
Height of max. drop	Inches	$114G^{1.75}$	$94.6G^{1.75}$
COMPRESSION PARALLEL TO GRAIN			
Fibre stress at P.L.	Pounds per square inch	5,250G	8,750G
Maximum crushing strength	Pounds per square inch	6,730G	12,200G
Modulus of elasticity	1,000 pounds per square inch	2,910G	3,380G
COMPRESSION PERPENDICULAR TO GRAIN			
Fibre stress at P.L.	Pounds per square inch	$3{,}000G^{2.25}$	$4{,}630G^{2.25}$
HARDNESS			
End surface	Pounds	$3{,}740G^{2.25}$	$4{,}800G^{2.25}$
Radial surface	Pounds	$3{,}380G^{2.25}$	$3{,}720G^{2.25}$
Tangential surface	Pounds	$3{,}460G^{2.25}$	$3{,}820G^{2.25}$

*The properties and values are to be read as equations; for example, modulus of rupture for green material $= 17{,}600G^{1.25}$ where G represents specific gravity, weight oven-dry, volume at moisture content indicated.

tion of the strength of a species when its average specific gravity is known, cannot be applied as accurately for the comparison of specimens of the same species. The table shows that the crushing strength in compression parallel to grain varies directly with the specific gravity, when the comparison is made between species, but when considering material from the same species, test results show that the relation is expressed by a higher power of the specific gravity. For example, in the general equation shown in the table for maximum crushing strength, air-dry, 12,200G, becomes $12{,}200G^{1.25}$ when the relation between maximum crushing strength and specific gravity is evaluated from samples from one species.

When wood is used in positions where strength is a consideration, and when the sizes and the moisture content are standardized, it is often possible to select the strongest material by specifying a definite minimum weight for the piece to be used. An example of this method of selection may be cited in the case of aircraft construction, where standard parts such as spars and struts may be selected on the basis of weight to secure material of satisfactory strength.

Sapwood and Heartwood

In trees of all species which have attained commercial size, there are two zones, more or less distinct, in the cross-section of the bole of the tree, namely, the heartwood and the sapwood. Heartwood is essentially dead inner wood that plays no part in the development of the tree other than to help support the outer living sapwood that provides the channels through which food and moisture are supplied to the cambium for the growth of the tree.

In many species of trees, the boundary between the heartwood and the sapwood is distinctly marked by change of colour; in others, the colours of heartwood and sapwood are so similar as to make differentiation of the two areas very difficult. Of the former type, a good example is larch; of the latter, white spruce and white birch are typical.

Although considerable difference of opinion as to the relative strength of sapwood and heartwood exists, the increasing volume of published data (5, 10, 28, 33, 37) indicates that no substantial change in

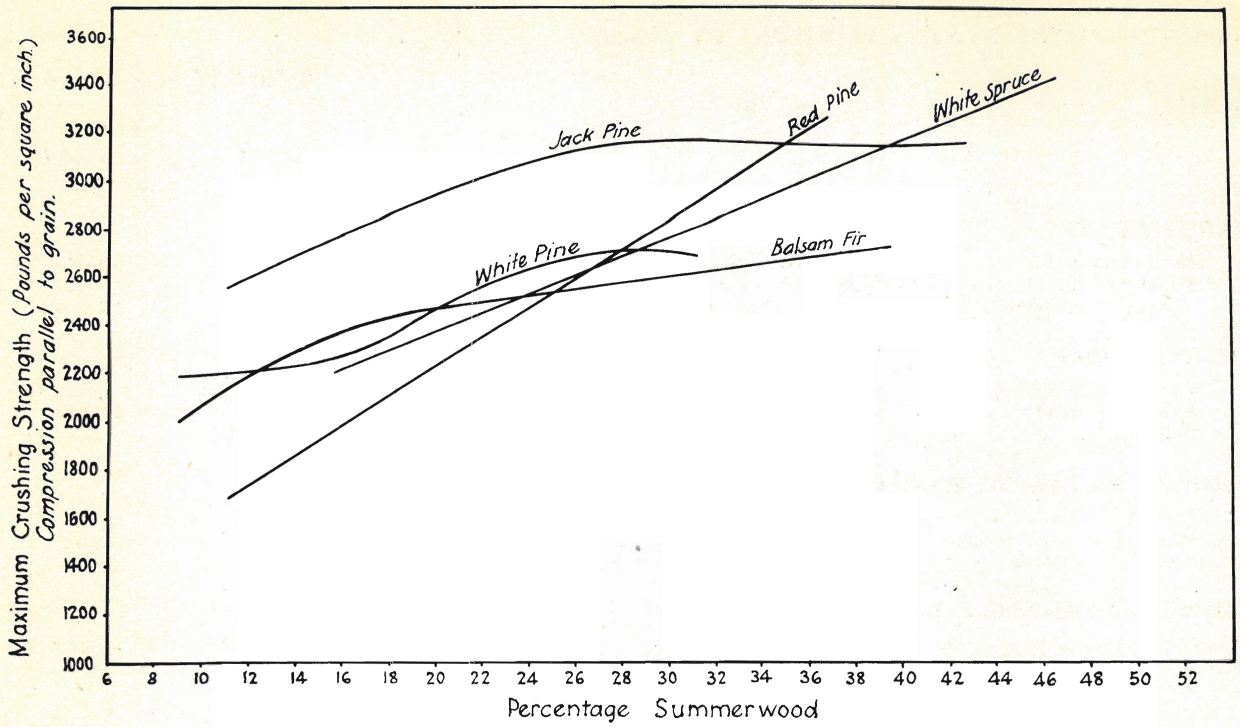


FIGURE 10.—Relation of Maximum Crushing Strength in Compression Parallel to the Grain to Percentage of Summer-wood for some Canadian Species.

strength occurs because of the transition from sapwood to heartwood. Since there is no apparent change in the cell structure, other than that caused by the infiltration of resins, gums, and other substances, this conclusion appears to be reasonable.

Rate of Growth

The growth of a tree is maintained by the addition each year of a layer of wood substance between the previously formed wood and the inner bark. The rate of growth of timber is determined by counting the number of these annual layers across a line drawn from the pith to the periphery of the tree, and is specified in terms of rings per inch.

There is no definite relation between rate of growth and strength in the sense that one is proportional either directly or inversely to the other (23). However, investigations (28) have indicated that:—

(a) For the softwoods, such as the spruces, pines, balsam fir, and Douglas fir, and for the weaker hardwoods, such as chestnut and the poplars, there is an optimum rate of growth for the production of timber of highest strength. This rate is not, of course, the same for all species.

(b) For the above classes of woods, the rate of reduction in strength from the maximum is less for slow-growth than for rapid-growth material.

(c) The diffuse-porous woods, such as birches, beech, and maples, do not show any marked differences in strength, whatever their rate of growth may have been.

(d) For the ring-porous woods, such as oaks, hickories, and ashes, the maximum strength values are associated with woods of rapid growth, and there is a considerable reduction in strength for material of excessively slow growth.

The opinion has sometimes been expressed that a rate-of-growth specification has little significance in the grading of structural timber (10). Instead of limiting the grade of timbers by having them conform to a rate-of-growth clause only, it would be advisable, where such a clause exists, to include also specifications as to the percentage of summer-wood (2).

Proportions of Summer-wood

The cells in summer-wood have thicker walls than the cells in spring-wood.

Within the same species it has been found that timber showing the greatest percentage of thick-walled material has the highest strength. For example, spruce having 40 per cent summer-wood is, in general, stronger than spruce having 20 per cent summer-wood. The same is true for Douglas fir and other species. It does not follow, however, that the strength values of spruce with 40 per cent summer-wood are greater than those of Douglas fir having 20 per cent summer-wood. Figure 10 shows, for a number of Canadian woods, the relation between the percentage of summer-wood and the strength. The general trend of the curves indicates that with an increase in the proportion of summer-wood there is an increase in strength.

This relationship between the percentage of summer-wood and strength has been used in the selection of timbers where high safe allowable working stresses are desirable. Grading rules for "dense" Douglas fir contain specifications regarding the minimum allowable percentage of summer-wood (2) as well as for rate of growth, the estimation for both these specifications being made by visual inspection of the ends of the timbers. Douglas fir is the only Canadian wood to which these specifications have been applied.

Locality of Growth

From the data so far available, it has been difficult to determine with any degree of definiteness the effect of locality of growth on the strength of timbers. While it is recognized that there may be considerable variation in the strength of timber from a species growing in widely separated parts of the country, similar variations in strength may be found in timbers from trees of the same species growing in the same locality (23). Conditions of soil, light, moisture, etc., have a very considerable influence on the growth of trees, and these conditions are likely to vary greatly within the same general locality.

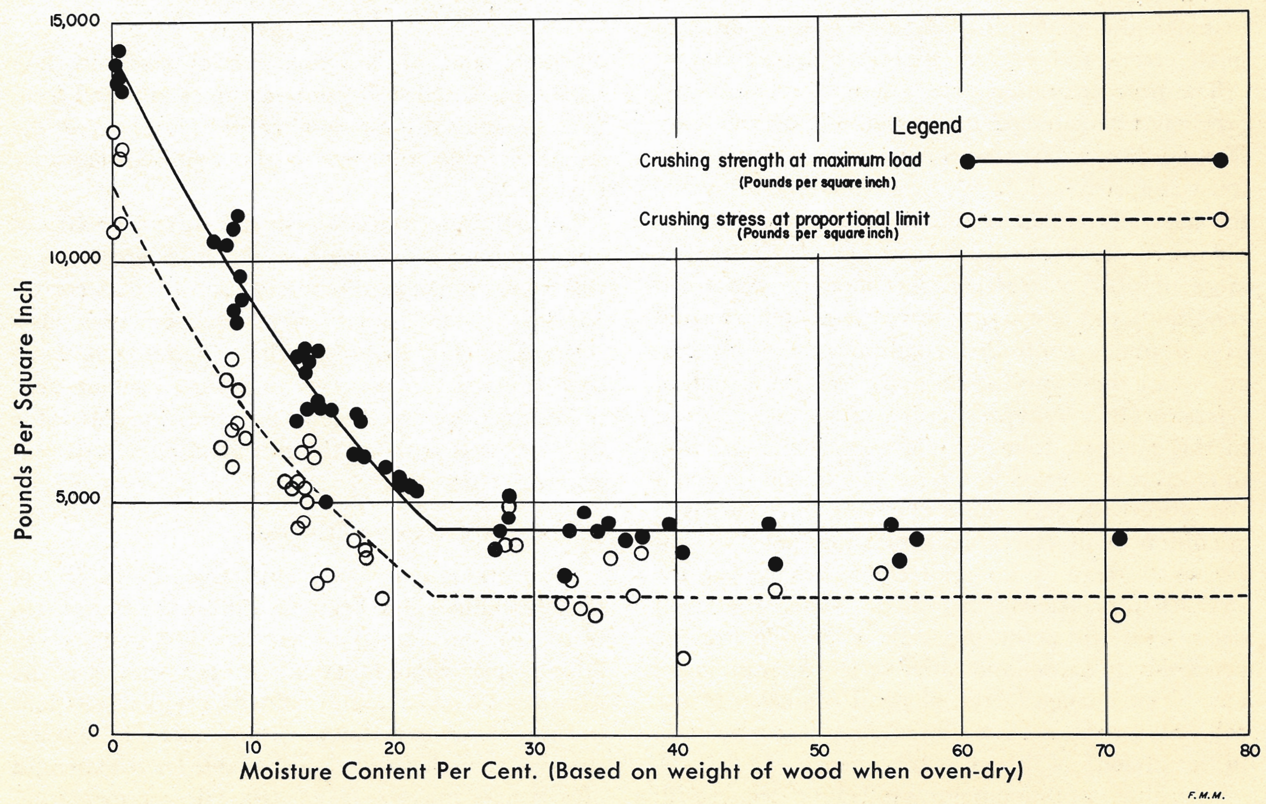


FIGURE 11.—Relation Between Crushing Strength at Maximum Load and Compression Strength at Proportional Limit in Compression Parallel to the Grain, and Moisture Content, for Douglas Fir.

Tree species have fairly definite geographical limits, and where these are natural boundaries with respect to conditions of growth it is found that the timber produced by a species near the limits of its distribution is inferior to that produced near the centre. However, the locality of growth may have considerable influence upon the strength properties of certain species. Douglas fir grown at low elevation in the humid areas near the Pacific Coast has strength characteristics different from that grown at high altitudes or in the drier interior belt of British Columbia. These differences in strength are sufficiently important to make it necessary to give separate strength values for timbers obtained from trees grown in the areas cited.

Moisture Content

The manner in which moisture affects the cells of wood has been explained in another chapter. The fibre saturation point becomes of great importance in the study of the strength—moisture content relationship, and its determination is a matter of importance (34). Several methods have been adopted to make this determination, all of which involve small errors and so give slightly different values.

The fibre saturation point cannot be determined precisely from strength tests because of the difficulty of obtaining for test purposes wood in which all the free water in the cell cavities has been removed, while the cell walls remain saturated. It may, however, be obtained with reasonable accuracy by testing a large number of matched specimens in the green condition, and at varying moisture contents during drying under controlled conditions, and plotting curves for these varying strength—moisture content relations (20). A typical graph of curves, obtained in this manner, from tests in compression parallel to grain is illustrated in Figure 11. It will be noted that during the early stages of drying from the green condition until the fibre saturation point is approached there is no appreciable change in the strength properties of the wood. When the wood dries below this point, the walls of the cells become progressively harder and stiffer with further moisture loss. This change in the physical condition of the cell wall is reflected in a general progressive increase in the strength of the wood specimen.

The fibre saturation point is difficult to locate with absolute precision from these graphs, because of the variations in test results to be expected from a non-homogeneous material such as wood. Two curves can be plotted, however, one through points representing strength—moisture content relations during the later stages of drying, and another charting the data when the wood is saturated. If these two graphs, the second of which is a straight line, are extended towards each other, they meet at what is called the intersection point. The moisture content at which this intersection takes place is accepted as the representative fibre saturation point, and its value is used in computations where this factor is involved.

From tests made in various laboratories, it has been found that, if the strength of a wood species is known at any two moisture contents, the strength at any other moisture content may be computed with a fair degree of accuracy, provided that this moisture content is not too far removed from that of the reference moisture contents. An exponential formula connecting strength and moisture content was devised by Wilson (39) and is now generally accepted. This formula may be expressed as follows:

$$\text{Log } S_3 = \text{Log } S_1 + \frac{(M_1 - M_3)}{(M_1 - M_2)} \log \frac{S_2}{S_1}$$

where S_1 and M_1 are one pair of corresponding strength and moisture content values as found from test; S_2 and M_2 are another pair; and S_3 is the strength value adjusted to the required moisture content M_3.

In computing these adjustments it is necessary, if one of the known strength values is for green material, that the moisture content used be that corresponding to the point of intersection previously referred to. For most Canadian species, this value approximates 25 per cent moisture content and, unless data are available to the contrary, this value may be used without the introduction of any important error.

Difference Between Species

An examination of the values given in Table 1 of the Appendix will indicate the differences in strength of the various Canadian woods. The value given for any particular function for each species is the average of a great number of tests. While variations in strength are to be found within individual species, the average values given in the table for the strength of a species may be taken as a fair representation of the strength of average clear material obtained from that species.

The values are for small, clear specimens, and show variations from 6,200 pounds per square inch for modulus of rupture in static bending, air-dry, for eastern white cedar to 19,400 pounds per square inch for the corresponding function for ironwood. Similarly, for compression parallel to grain values, the variation between species is exemplified by the difference between the values obtained from eastern white cedar and ironwood. The resistance to crushing of the former species is 3,530 pounds per square inch, while that of the latter is 8,960 pounds per square inch.

Strength values for structural-size timbers of the different species tested do not show the same extremes as do the small, clear specimens. This is accounted for by defects such as knots, checks, and shakes, which in the great majority of cases are the factors limiting the strength of structural timbers. As these defects are common to all timbers, without regard to species, they tend to reduce the range of the strength values; a further reduction is introduced when safe allowable working stresses are assigned to the different species (Appendix, Table 2).

Differences Within the Same Species

Wood, being non-homogeneous, naturally has greater variations in its strength than would be expected of a homogeneous material. These variations, however, can be estimated, and allowance is made for their existence in determining working stresses for any species. Figure 12 shows the percentage variation in the modulus of rupture of a shipment of white pine, consisting of ten trees from the same site, tested in static bending in the green condition. The

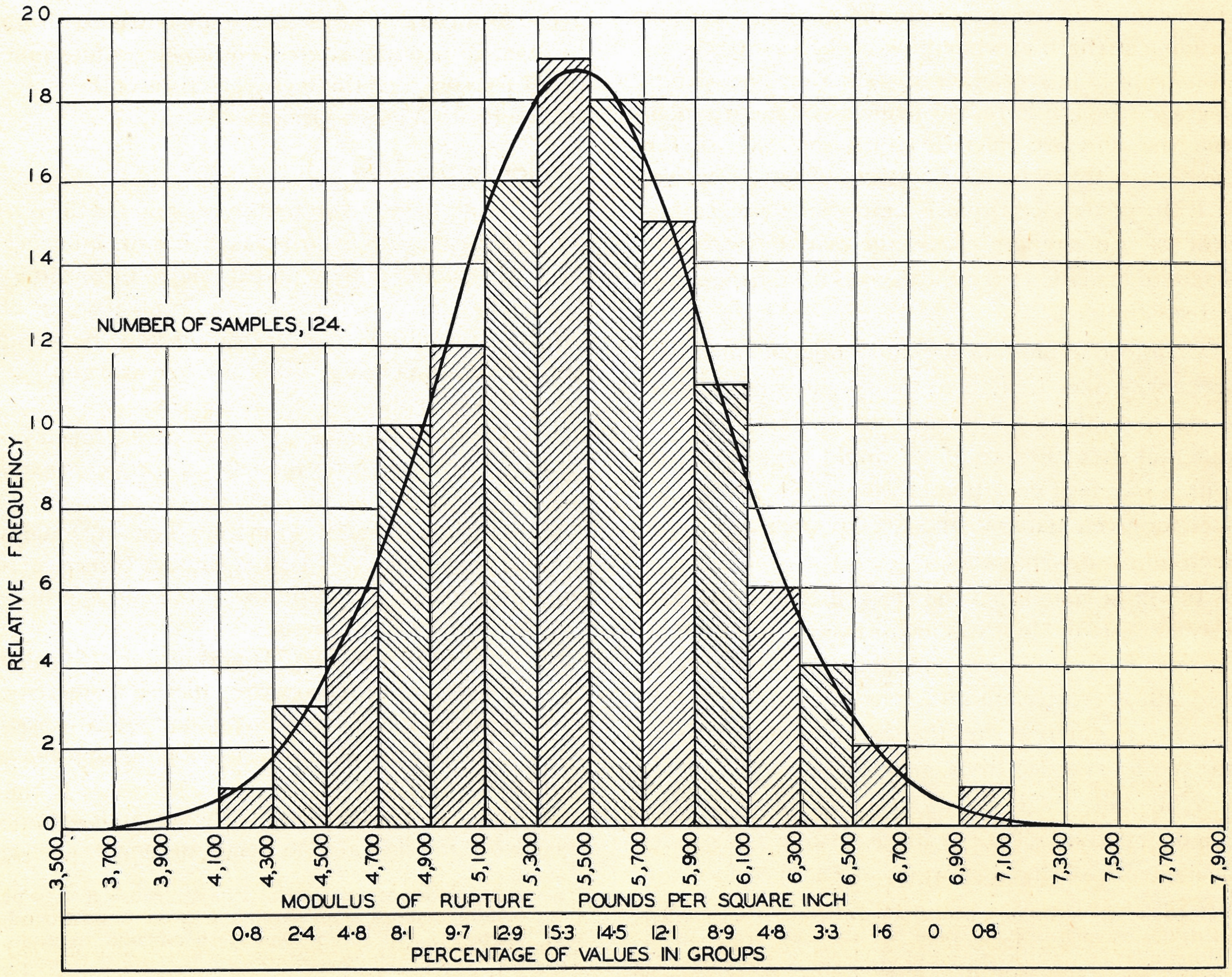


FIGURE 12.—Variability of Bending Strength in a Shipment of Green White Pine.

arithmetic mean of the test results obtained from one hundred and twenty-four samples was 5,450, the maximum value was 6,956, and the minimum 4,200 pounds per square inch. It will be noted that in this instance the distribution is symmetrical about the mean. The standard deviation[1] is 528 pounds per square inch and, for this sampling, approximately 70 per cent of the values fall within one times the standard deviation on either side of the mean, that is, between 4,900 and 6,000 pounds per square inch.

Figure 13 shows the variation from the species average in bending strength (modulus of rupture in static bending) in green white pine. The species average is 5,110 pounds per square inch, and the standard deviation on either side of the average, within which 71 per cent of the values lie, is 800 pounds per square inch. Ninety-one per cent of the strength values lie within twice the deviation from the mean. The variation from the species average in bending strength in white pine in the air-dry condition, as used in service, is also shown. The species average strength is 10,350 pounds per square inch, and the standard deviation on either side of the average, within which 69 per cent of the values lie, is 1,710 pounds per square inch. Ninety-seven per cent of the strength values lie within twice the standard deviation from the mean, i.e., 3,420 pounds per square inch.

If, instead of plotting strength values of individual specimens, the strength of the species were plotted using the values of the strength of trees from the different sites, the variability would have been less, with a standard deviation of 648 pounds per square inch for green material, and 1,630 pounds per square inch for air-dry material.

It will be noted that the variability in strength is greater in individual specimens from a species than in trees from a species, and that the variability in strength is greater within a species sampled from a number of different sites than in one shipment from the species sampled from one area.

While fairly high variations are found among the minor test results, large variations from the species average in all the important strength values are rare[1]. As an example, the maximum variation from the average bending strength of air-dry white pine was 51 per cent, and this is characteristic of the major test results from other species.

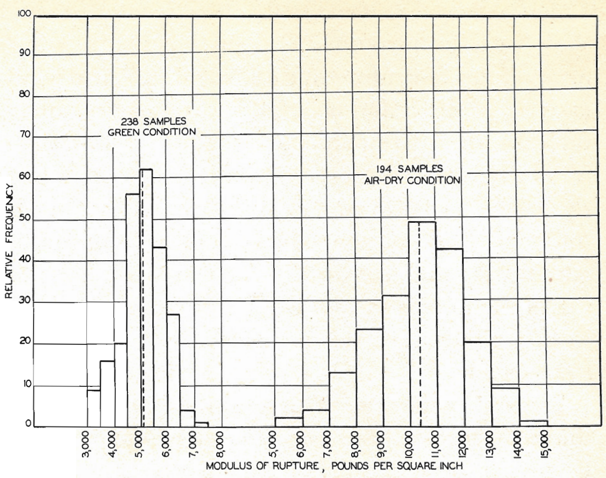


FIGURE 13.—Variability of Bending Strength in Specimens of White Pine.
(Arithmetic mean indicated by dotted line).

Position in the Tree

While tests have shown that the position in the tree from which the specimen is taken has an influence upon the specific gravity and strength, these differences have not been sufficiently consistent or of sufficient magnitude to warrant placing too great emphasis upon position within the tree as a guide to strength properties.

The test data available are fairly consistent in indicating that there is an increase in specific gravity and in the major strength properties in passing from the pith to the periphery of the tree. Tests of Douglas fir (32), white spruce (14), Engelmann spruce, and Sitka spruce (6) have all shown this increase in both specific gravity and strength.

Reports of tests on ash (33) and hickory (5) show that, for some strength properties, there is an increase towards the periphery, reaching a maximum at from 3 to 7 inches from the pith and decreasing again towards the periphery.

The data on the variation of the strength properties of wood in relation to its height in the tree show a

[1] The standard deviation is a measure of dispersion in a normal distribution such that one times the standard deviation on either side of the arithmetic mean will include approximately 68 per cent of the samples, twice the standard deviation will include 95 per cent, and three times will include 99 per cent.

[1] The more important mechanical tests are considered to be static bending, compression parallel to grain, impact bending, toughness, and compression perpendicular to grain. The minor tests include hardness, shear parallel to grain, cleavage, tension parallel to grain, and tension perpendicular to grain.

considerably less definite trend than do the data for the strength of wood in relation to its radial position. Douglas fir, hickory, and ash have greatest strength at positions 10 to 30 feet from the butt of the tree, the strength in each case decreasing slightly towards the butt and decreasing to a greater extent towards the top of the tree. White and Engelmann spruce, however, show an increase in specific gravity from the butt to the top. Tests on white spruce also indicate a progressive increase in strength from butt to top, although the differences in both specific gravity and strength were not of very great magnitude.

Where structural-size timbers are considered, the position in the tree from which the timbers are cut does not in itself directly influence their strength appreciably. However, the timbers cut from the lower part and near the periphery of large trees are likely to contain fewer knots than those obtained either near the pith in the lower portion or from any section of the upper portion of the tree, and, as knots have a weakening effect upon timbers, it may follow that position in the tree does indirectly have an influence upon the strength of timbers (10).

Age of the Tree

It is difficult to state with any degree of certainty the effect that the age of a tree has upon the strength of the timber into which it is converted. While the small, clear specimens tested at the Forest Products Laboratories were obtained from trees which varied in age from 21 years to 405 years, an analysis of the resulting data did not show any definite relationship between strength values and the age of the tree from which the material was taken, but this cannot be taken as conclusive proof that such a relationship does not exist. The method of sampling used in

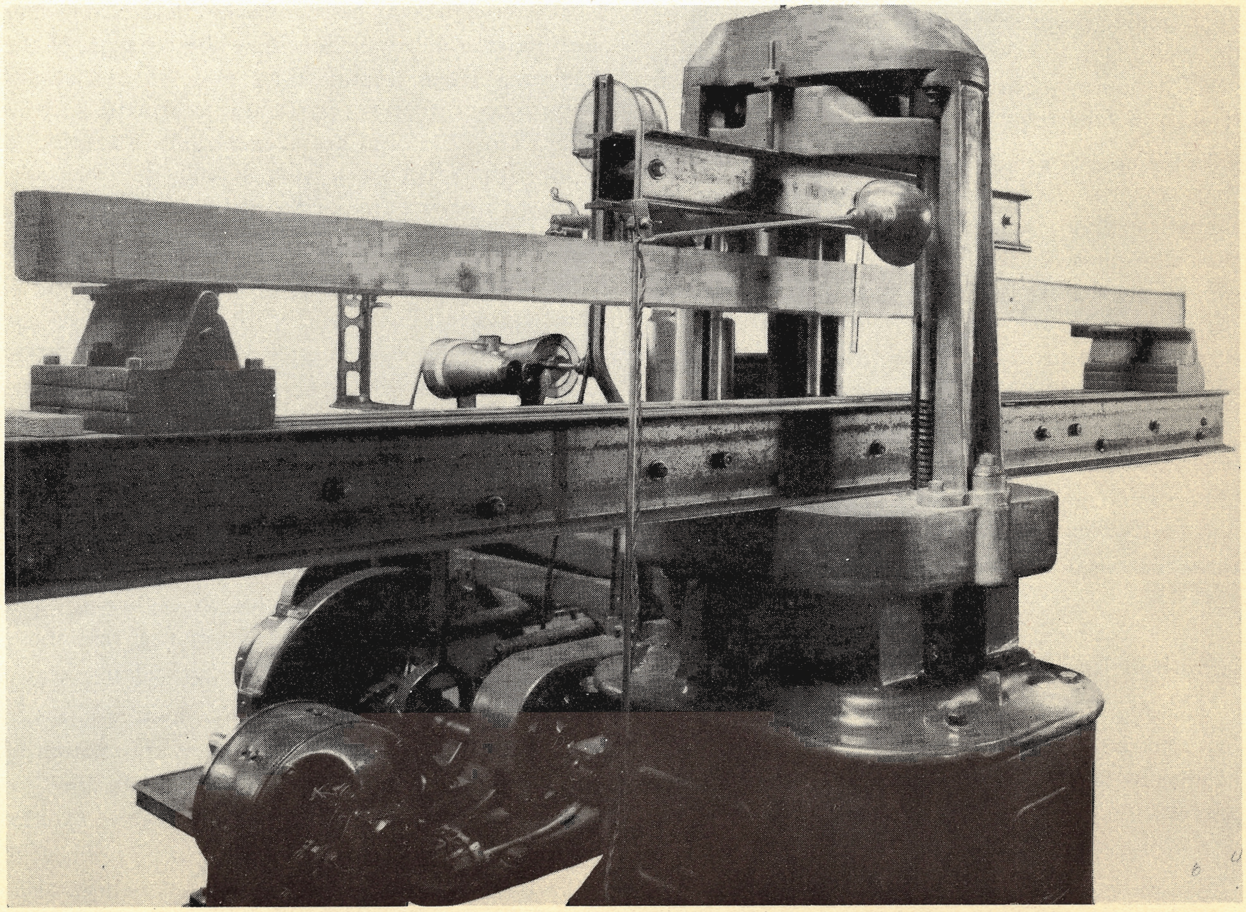


Plate 47.—Determining Strength of Cross-arms.

determining the physical properties of wood does not utilize all of the cross-section—from pith to periphery—of a tree, and data as to the exact age of test specimens are therefore lacking.

It would seem reasonable to expect that, so long as a tree develops under favourable conditions and maintains vigorous growth, the wood so formed would possess at least the average mechanical properties associated with the species. As a tree grows old, however, it eventually succumbs to one or more of the forest hazards, such as fire, wind, insects, or fungous growth, and in many cases it is difficult to obtain over-mature trees not affected by at least the last.

It has been reported (13) that the average life of a merchantable stand of mature Douglas fir, Coast type, is approximately 400 years, although trees of much greater age have been found. As Douglas fir is one of Canada's longest-lived trees, most other species would have a shorter average life. In trees approaching maturity for the particular stand or for the particular species, the presence of decay, suppression of growth, or loss of vitality would naturally tend to weaken the wood.

In the case of western red cedar, it was found (21) that material from pole-size trees had, on the average, higher strength and specific gravity values than that obtained from old trees. In an investigation of the density of white spruce it was reported that "maturity and age or size (or both) seem to contribute toward the production of light-weight wood" (14). The opinion has been expressed that "as a general rule, in the species which show a variation in the mechanical properties with position in cross-section there is a certain age at which densest and best wood is produced, while at over-maturity the wood put on is somewhat inferior mechanically" (24).

Length of Time in Service

The length of time a timber under load remains in service is usually dependent upon its freedom from conditions favourable to the development of fungal attack (decay or rot), or upon the period of usefulness of the structure of which it forms a part.

All timbers "weather" or "age" when exposed to the elements, but this weathering must not be confused with decay. If decay is not present when timbers are put in service and conditions are such that subsequent infection does not take place, then the length of time that the timbers remain in service has no apparent effect upon their strength, provided they are not subjected to excessive loads or to surface wear caused by the abrasive action of wind-borne sand, or by the effects of ice or other physical agencies. This is confirmed by tests of Douglas fir bridge timbers removed after 20 years' service and joists after 43 years (1), also of Douglas fir telephone cross-arms after line service of 5, 10, 15, 20, and 25 years (35). These tests have shown that the strength of these timbers is practically the same as the strength of freshly cut timbers of the same species. The reduction in cross-section caused by weathering will affect in some degree the load-carrying capacity, especially of smaller timbers, if the weathering is severe.

Defects

From the mechanical standpoint, defects in timber are imperfections which reduce the strength of the timber. These imperfections may be due to (a) variations of structure incidental to growth, such as knots, cross or spiral grain, inclusions of bark, and resin pockets, (b) forest hazards, such as frost splits, insect or fungous attack, lightning, windfall, or fire scars, (c) defects incidental to manufacture, such as felling shakes or breaks, picaroon holes, torn grain, cross-grain due to non-parallel sawing with the fibres of the wood, inclusion of wane in the cutting of the timbers, seasoning checks and shakes, warping, case-hardening, or collapse in seasoning, or (d) fungous attack due to improper conditions of storage or use.

In tests of 1,215 seasoned white spruce joists (29) of sizes ranging from 2 by 4 inches to 3 by 9 inches, carried out at the Laboratories, the following summary, Table 9, shows the number of the above defects which were responsible for failure.

The strength of the timbers in which failure was caused by the presence of defects was approximately 88 per cent of that for the timbers which failed for no apparent cause. The average modulus of rupture was 6,200 pounds per square inch, or 80 per cent of that obtained from tests of small, air-dry, clear specimens. This value is higher than that usually

TABLE 9

CAUSES OF FAILURE IN 1,215 AIR-DRY WHITE SPRUCE JOISTS

DEFECT	SIZE OF JOIST						NUMBER	PER CENT
	2″x 4″	2″x 6″	2″x 8″	2½″x 7″	3″x 6″	3″x 9″		
KNOTS	169	162	144	149	192	108	924	76.1
CROSS-GRAIN	18	19	14	21	7	10	89	7.3
SPIRAL GRAIN			4	1	6	7	18	1.5
DISTORTED GRAIN	1	2	1				4	.3
CHECKS			1	2	2	11	16	1.3
SHAKES		1		3	6	28	38	3.1
PITCH POCKETS	1				1		2	.2
DOTE			1				1	.1
CAUSE NOT APPARENT	11	15	29	21	11	36	123	10.1
	200	**199**	**194**	**197**	**225**	**200**	**1,215**	**100**

obtained from timbers containing defects, and may be accounted for by the fact that the grade was fairly high and that the timbers were of small width. This indicates, in some measure, the effect of defects upon the strength of timbers in bending. It must be remembered, however, that the effect of defects upon the strength of timber is very variable, depending upon such things as the manner in which the timber is used, the size and nature of the defect, and its position in the timber.

The relation between the strength of clear specimens and specimens with defects has been reported in Forest Service Bulletin 108, United States Department of Agriculture, Tables 1, 2, 11, and 12. An analysis of these data shows that, for modulus of rupture in bending in the green condition, the structural-size timbers with defects have approximately 70 per cent, and in the air-dry condition approximately 60 per cent, of the strength of the clear specimens of corresponding moisture content. In from 80 to 90 per cent of all tests of structural-size specimens, failure is due to the presence of defects.

The effect of the more important defects on the strength of timbers is as follows:

Knots.—Knots are the major factor in reducing the strength of timbers, because of their very frequent occurrence and the high impairment of strength for which they are responsible. The extent of the strength reduction is governed largely by the position and size of the knot, the nature of the test (compression or bending), and the amount of distorted grain around the knot.

In beams, knots located on or near the edges of the portion of the beam under greatest stress have the greatest weakening effect. The failure may occur at comparatively small knots on the centre edge rather than at larger knots located elsewhere in the beam. Of course, the larger the knot at this critical location, or the greater the amount of distorted grain around it, the greater becomes the weakening effect.

The reduction in modulus of rupture in static bending for green and air-dry structural-size timbers was found to be approximately 30 per cent and 40 per cent respectively of the corresponding value for the clear specimens (10). The reduction in these same values for joists was found to amount to about 35 per cent and 45 per cent respectively, and, as noted in Table 9, approximately 75 per cent of the failures were due to knots.

While the majority of grading rules do place limits upon the size of knots, in some cases the specifications as to both their size and location are not sufficient to permit grading the timbers into their proper strength classes.

It has been found, however, that some grading rules prepared specifically for the purpose of selecting timbers in accordance with their appearance do select timbers in reasonable accordance with their strength characteristics also. Specifications for structural grades have been published by several authorities, including the Canadian Standards Association (Serial Designation A43-1937).

Cross- and Spiral Grain.— Cross-grain occurs in timbers which have not been sawn parallel with the fibres and can, as a rule, be detected by visual inspection of the timber. Spiral grain occurs in timbers cut from trees in which, as a result of peculiarities of growth, the fibres are arranged spirally instead of vertically. Spiral grain is difficult to detect by visual inspection.

While cross- or spiral grain is responsible for considerably fewer failures in structural timbers than are knots, the magnitude of the strength reduction may be considerably greater. As shown in Table 9, approximately 9 per cent of failures were due to cross- or spiral grain. However, the strength reductions, below that for joists failing through no apparent cause, were 40 per cent.

An analysis showed that the average slope of the grain causing failure was one in nine. While this is considered an excessive slope, it was apparent from an examination of the joists that where the slope was less than this the failure usually occurred at a knot (3). The distorted grain around knots which extended to the edge of the joist, causing a failure, was not considered as a cross-grain defect, but rather as a knot defect. In the grading of structural timbers it is usual to specify a limiting slope of the grain from the long axis of the timber.

Shakes and Checks.—The presence of shakes or checks reduces the resistance of a timber to horizontal shear stresses; the former, which are usually separations between annual rings, occur both in the green and in the seasoned timbers, and the latter are usually found in seasoned or partially seasoned timbers.

Horizontal shear failures, except in the case of deep, narrow beams, can be attributed usually to shakes or checks. As noted in Table 9, 4.4 per cent of the failures of the joists were due to shakes and checks, and in every case the failure was in horizontal shear. In the grading of structural timbers, the limitations as to the extent and severity of shakes and checks are based upon the reduction of the area resisting horizontal shear.

Worm-holes.— Experiments have shown that, in mild cases of infestation, worm-holes have no more effect than knot holes of the same size (36). At the edges of joists or beams, their effect is significant, and timbers where they occur should be regarded with suspicion, particularly if several holes occur together. In posts or columns, the worm-holes, if scattered, will have little effect upon the strength. If concentrated over a small area of the cross-section, the worm-holes will weaken the post by an amount equivalent to the reduction in cross-section caused by the removal of the wood by the borers. The reduction in strength will rarely be significant unless the infestation is acute.

Miscellaneous Defects.— Under this heading, such defects as broken grain, picaroon holes, worm-holes, felling breaks, pitch pockets, frost splits, and insect injuries are included. These defects are present in mill-run timbers, but are not found to any great extent in properly graded structural timbers, where failures from such causes are infrequent. As will be noted in Table 9, failures due to these miscellaneous defects amounted to only 0.6 per cent. Even though these defects may occasionally occur in structural timbers, they are usually not serious enough to cause failure. In the grading of timbers it is usual to specify that these defects shall not be present in such numbers or in such positions as to materially affect the strength of the timbers.

Decay.—From strength considerations, decay is, perhaps, the most serious defect in timber. Fungous attack resulting in decay may occur at any time in the service life of the timber when conditions favourable to fungous growth obtain. The conditions governing the infection and the degree of severity of decay are so varied that it is extremely difficult to present strength data that will adequately represent the effect of decay upon the strength of woods.

Tests made on a special shipment of jack pine joists showing red stain, the result of infection with the fungus *Fomes pini*, indicated that the red staining did not cause failure, nor were the strength values below those of unstained jack pine. An investigation of the strength and spike-retention properties of jack pine ties (30) showed that the red-stained condition did not adversely affect either of these properties, but that in the "red-rot" condition, as determined from a visual inspection of the ends, there was a reduction for these properties of from 15 to 25 per cent, the reduction depending upon the degree of severity of the decay.

Fungi require favourable conditions of temperature and moisture to develop (11, and see Chapter 6, Decay and Stains in Wood). If these conditions are never present after a timber is placed in service, reductions in strength owing to decay, will, of course, not occur.

Decay, with subsequent loss in strength, may be anticipated in untreated timbers in locations such as the ground-line of poles or posts; the vicinity of the water-line of wharves, piling, or other partially submerged timbers; mud sills of bridges; joists and beams in foundations (unless properly ventilated); roofs of such buildings as textile mills and pulp and paper mills, where humidity is high; fastenings, bolt-holes, etc., where water may collect.

Air-seasoning

When the moisture content of green timber has been reduced below the fibre-saturation point, an increase in strength takes place. From the values given for small clear specimens of Canadian woods in the green and air-dry conditions (28) the average increase in strength of the air-dry specimens, as compared with the green specimens, is given in Table 10.

TABLE 10

PERCENTAGE INCREASE IN THE STRENGTH VALUES OF SMALL CLEAR SPECIMENS DUE TO AIR-SEASONING

KIND OF TEST	PERCENTAGE INCREASE	
	Softwoods	Hardwoods
Static bending, modulus of rupture	68	64
Compression parallel to grain, maximum crushing strength	101	97

For structural timbers, increases in strength of the magnitude shown above for small, clear specimens are not usually obtained. This is accounted for, principally, by the irregular seasoning of the large timbers, in which the outer portions, drying more quickly than the inner, reach the fibre-saturation point and commence shrinking in advance of the inner section. Unequal stresses thus set up are relieved by checks, shakes, warping, cupping, loosening of knots, or honeycombing, and the natural increase in strength inherent to the wood is dissipated in varying degrees because of these defects.

The average increase for modulus of rupture in static bending of carefully seasoned joists is approximately 30 per cent, as compared to approximately 65 per cent for the small, clear specimens of the same species.

In an investigation carried out by the United States Forest Products Laboratory, similar results were obtained, except that the increases in strength of the seasoned structural timbers were not as great as those shown for the joists tested at the Canadian Laboratories (10).

If timbers containing seasoning defects are used in positions where they will return to a wet condition, their strength will be below that of green timbers. It is therefore considered better practice in the construction of docks or other structures where timbers are completely or partially submerged to use timbers that have not been air-seasoned.

Kiln-drying

The kiln-drying of timbers may be undertaken: (a) to secure a moisture content below that obtainable by air-drying, (b) to obtain an air-dry moisture content in a shorter period of time than is possible by ordinary air-seasoning methods, (c) to reduce the moisture content of green lumber, thereby permitting shipment at low weight without the necessity of storage for partial seasoning (7). It has been shown that air-seasoning, in many cases, results in the unequal drying of large-size timbers, with resultant lowering of strength factors owing to checks and shakes so induced. Since kiln-drying performs exactly the same function as air-seasoning, but under controlled conditions, the tendency towards unequal drying is lessened. Where kiln-drying is carried out under proper schedules (8), the resulting loss of strength due to drying defects is usually not so severe as for air-seasoning. Where, however, kiln-drying is not carried out under proper schedules, the resulting loss of strength may be even greater than that occasioned by air-seasoning. The defects causing this loss of strength are similar to those occasioned in air-seasoning, for example, case-hardening, resulting in checks and honeycombing. If too high temperatures are used the wood becomes very brash. An investigation carried out by the United States Forest Products Laboratory to determine the effect of kiln-drying on the strength of woods (40) indicated:

> "(a) That wood may have its strength properties, particularly toughness or resistance to shock, quite seriously damaged without any *visible* evidence of such damage.
>
> "(b) That the effect (on strength) of a given process (kiln-drying schedule) is not the same for all species of wood.
>
> "(c) That apparently a given process (kiln-drying schedule) may be entirely safe for

some, but quite detrimental to other, material of a species.

"(d) That proper kiln-drying produces material fully equal in all strength properties to that resulting from air-drying under the most favourable conditions."

Preservative Treatment

When timbers are to be used in locations favourable to decay, it is considered good engineering practice to treat these timbers with some preservative which will prevent the development of decay for a considerable period.

As stated elsewhere, creosote has been used extensively in the preservative treatment of timber (9). Since this preservative retards decay, it is evident that timbers so treated, used in positions favourable to decay, will maintain their initial strength over a longer period than timbers which are used in similar positions untreated. It is, however, necessary to know whether the treated timbers have suffered any initial loss in strength as a result. A considerable number of investigations (41) was carried out from 1909 to 1918 to determine whether there was any strength reduction caused by commercial preservative treatments. The tests showed that the treatments at that period were, in some instances, very severe, resulting in strength reductions as high as 35 per cent. However, improved methods of treatment (15) have greatly reduced this loss in strength. Tests carried out at the Laboratories (16, 17) on creosote-treated and untreated Douglas fir beams, give the results shown in Table 11.

The summary table below shows the percentage reduction in strength due to incising and to treating, both separately and jointly. It should be noted that the total reduction (in modulus of rupture, for example) for both incising and treating is thirteen per cent, whereas the reduction for incising is seven per cent, and the reduction for treating alone is thirteen per cent. On first thought it might be considered that the reduction in strength on account of incising and treating should be equal to the total of the reductions effected by incising and by treating when determined independently. This, however, is not the case, because incising before treatment, by relieving the stresses set up by the treating process, decreases to a certain extent the checking which results when creosoting timber which has not been incised. A charge of beams, in which only a part had been incised, showed more severe checking in the unincised timbers.

The results of tests on Douglas fir ties showed that, when they have been incised and treated with creosote in accordance with the present standard commercial treating schedule, their strength in resistance to crushing perpendicular to the grain is not appreciably changed.

While, in the course of a study of treated and untreated telephone poles, treated red pine poles showed an apparent reduction in strength of approximately 3 per cent, as compared with untreated poles from the same area, the fact that the specific gravity of the treated poles was slightly lower probably accounts for the reduction (31).

From an analysis of the available data it would appear that the strength of treated timbers is not affected by the creosote itself, but by the processes necessary to obtain penetration of the creosote into the wood (18). The more resistant the wood is to penetration, the more severe the treatment necessary, with resultant greater possibility of strength reduction.

Other preservatives are being used for the treatment of timbers, telephone poles, and power poles, and further study will be necessary before their effect

TABLE 11

PERCENTAGE REDUCTION IN STRENGTH DUE TO CREOSOTING AND INCISING OF DOUGLAS FIR

	MODULUS OF RUPTURE	HORIZONTAL SHEAR	FIBRE STRESS AT PROPORTIONAL LIMIT	MODULUS OF ELASTICITY
Reduction due to incising	7	7	4	4
Reduction due to treating	13	13	11	6
Reduction due to incising and treating	13	13	13	8

upon the strength of the wood can be properly determined; since the treatments are not more drastic than that associated with creosote, it is unlikely that their effect will be more deleterious. Among the more recently introduced preservatives are a number of proprietary chemical mixtures based on copper and arsenic salts, and on toxic phenolic compounds.

Many timbers have been treated with zinc chloride. Investigation has disclosed that in concentrated solutions timber is damaged by zinc chloride, but that the weakening effect of impregnation by the concentrations used commercially for preservative treatment is negligible unless the timber is overloaded, in which case it tends to fail with a brittle fracture.

Fire-retardant Treatment

Fire-retardant treatments may be either in the form of surface applications, such as fire-retardant paints, or by impregnation of the wood with chemicals. Surface treatments have little if any effect upon the strength of the wood. The impregnation of wood with chemicals to act as fire-retardants is, in most cases, carried out under much the same procedure as for preservative treatments of wood with chemicals against fungous attack. The conditions, such as degree and duration of temperatures, pressures, etc., under which the fire-retardant treatments are carried out are not in general more severe than for preservative treatments.

There has, however, been used in both commercial and experimental treatments such a wide variety of chemicals, such as sodium carbonate, sodium bicarbonate, oxalic acid (38), ammonium salts, and zinc chloride (4, 27) in strong solutions, some at least of which tend to reduce the strength of wood, that there is some basis for the belief that woods treated with fire-retardants are weakened, particularly in their ability to resist impact loads. To date, however, the great majority of woods treated to resist fire are used in such positions and sizes that strength is not a major consideration.

STRENGTH OF TIMBERS AND TIMBER PRODUCTS

Structural Timbers

Broadly speaking, timbers used in locations where strength is a factor may be termed "structural timbers". The more important Canadian timbers are listed in Table 2 of the Appendix. Structural timbers can be roughly classified by the terms applied to them in construction work—joists, beams, columns, poles, piles, ties, cross-arms, mine timbers, bridge timbers, sills, bearing blocks, and mill floors. Data on the strength of some of these structural items follow.

Joists.—Tests have been carried out at the Forest Products Laboratories of Canada on joists of white spruce, balsam fir, Douglas fir, jack pine, red pine, white pine, eastern hemlock, and western hemlock, in both green and air-dry condition.

The values for fibre stress at proportional limit, modulus of rupture, modulus of elasticity, and shear were computed from such tests. The minimum computed value for fibre stress at proportional limit for any species, even in the green condition, is not less than the value given it in Table 2 of the Appendix as a safe allowable working stress, and the air-dry test values when compared with the safe allowable working stresses assigned to the different species provide a generous factor of safety.

Beams.—Beams are subjected to bending stresses similar to those which joists have to sustain, but it is usual to apply this term only to the larger sizes of members subjected to cross-bending loads. Theoretically, tests on beams should give the same stress values as tests on joists. Actually, however, there are usually some differences in the resulting test data.

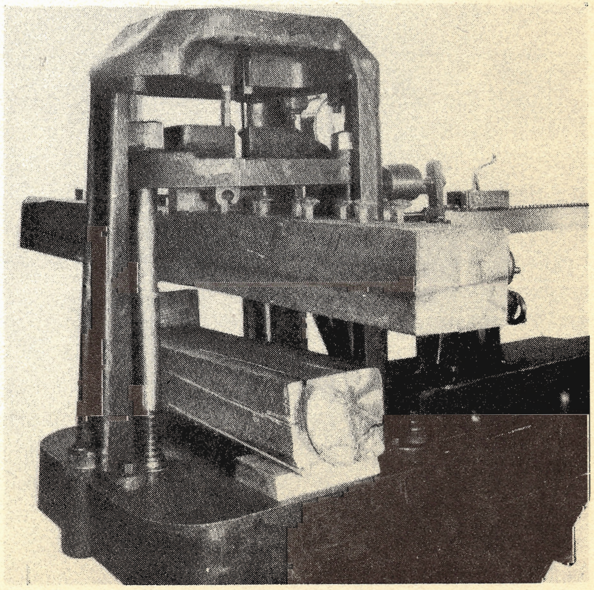


PLATE 48.—Testing Spike Withdrawal Resistance of Railroad Ties.

These differences are accounted for principally by the increased difficulty in seasoning the large-size timbers without inducing more serious defects than in the timbers of joist size. Tests on both joists and beams, however, have indicated that it is unnecessary to assign different working stresses to the different sizes of cross-bending members, since the same result can be achieved by altering the size of permissible defect in grading rules prepared for the selection of timber for beams and stringers, or for joists and planks.

In addition to bending stresses, beams are subjected to bearing stresses which are perpendicular to the grain of the wood. Recent investigations indicate that the position of the point of application of such bearing stresses influences the resistance of the beam to crushing. If the stress is applied at the extreme ends of the beam, its resistance to crushing may be considerably less than if the point of application of the stress is some distance away from the end.*

Columns *(square and rectangular).* —Columns may be classed as short, intermediate, and long, according to the value of the ratio of "length" to "least dimension". This classification is summarized below:

Class of Column	Approximate Ratio of Length to Least Dimension
Short	Up to 10
Intermediate	11 to 22
Long	Over 22

The loads on the short columns produce a crushing effect without any apparent flexure, whereas for intermediate and long columns under load, considerable flexure takes place. As noted in Table 3 of the Appendix, the load which columns are capable of supporting with safety decreases very rapidly as the slenderness ratio $\frac{L}{D}$ is increased. A report of tests carried out at the United States Forest Products Laboratory (25) states that:

> "In long columns, where stiffness instead of crushing strength is the controlling factor, the loss in strength on account of knots is relatively small as compared to that for shorter specimens. The loss would be negligible in long columns of the common grade having a slenderness ratio of 30 or more to 1 and in high-grade columns with a slenderness ratio of approximately 20 to 1.
>
> "The effect of knots on the strength of short columns is proportional to the reduction in cross-sectional area that would result if all the knots in any 6 inches of the length were removed from the cross-section.
>
> "A column with a slenderness ratio of 11 to 1 will sustain the same load as a shorter column of the same cross-sectional area.
>
> "Long columns: Within the elastic limit of the material the best interpretation of the behaviour of long columns is the Euler formula.
>
> "The decrease in cross-section of an Euler column, on account of seasoning, largely offsets the increase in strength which accompanies the seasoning.
>
> "Intermediate columns: The most practical expression of the behaviour of intermediate columns appears to be the Forest Products Laboratory fourth-power formula."
>
> (This formula is explained in the Appendix.)

Round columns.—The strength of round columns may be considered the same as that of square columns of the same cross-sectional area. In long, tapered columns, the strength may be assumed as identical with that of a square column of the same length, and of cross-sectional area equal to that of the round timber measured at a point one-third its length from the small end. The stress at the small end must not exceed the allowable stress for short columns.

In Table 3 of the Appendix "Safe allowable working stresses for columns", the United States Forest Products Laboratory fourth-power formula has been used for intermediate columns and the Euler formula for the long columns.

Poles and Piling

Poles.— Wooden poles are used extensively for telephone, telegraph, and power lines, the more important species used being western red cedar, eastern white cedar, jack pine, red pine, lodgepole pine, and Douglas fir. Tests carried out on poles at the Forest Products Laboratories (19, 26) have yielded data given in Table 12.

Poles are subject to defects in much the same manner as squared timbers, but not to the same

*The effect of loading near end of specimen upon sustained load at proportional limit in compression perpendicular to grain. Report (unpublished) by D. Osmun and W. E. Wakefield, Ottawa Laboratory.

SUMMARY OF RESULTS OF TESTS ON TELEPHONE POLES

TABLE **12**

	EASTERN WHITE CEDAR	JACK PINE	RED PINE	RED PINE (creosoted)	LODGEPOLE PINE	LODGEPOLE PINE (creosoted)	DOUGLAS FIR	DOUGLAS FIR (creosoted)	WESTERN RED CEDAR
SPECIFIC GRAVITY (Volume at test weight oven-dry)	0.313	0.415	0.375	0.356	0.446	0.425	0.413	0.413	......
RATE OF GROWTH (rings per inch)	31	17	13	12	16	13	6	6	18
AGE OF TREE (years)	174	88	66	58	84	69	31	30	......
SAPWOOD (per cent of total area)	20	49	84	82	55	48	59	58	21
SAPWOOD (depth in inches)	0.7	1.5	3.1	2.7	1.7	1.7	1.7	1.7	......
MOISTURE CONTENT AT POINT OF FRACTURE	82	47	87	20	45	18	31	19	20
MOISTURE CONTENT OF HEARTWOOD AT POINT OF FRACTURE	71	37	39	38	27	25	31	28	......
MOISTURE CONTENT AT TOP OF POLE	19	21	32	......	22	13	29	14	......
WEIGHT OF POLE (average)	331	397	409	429	399	403	422	488	300
DIAMETER AT LOAD POINT	10.4	9.8	9.6	9.3	9.9	9.9	10.0	9.9	9.7
DIAMETER AT TOP	6.8	8.0	7.8	7.5	8.1	7.9	8.3	8.3	......
MAXIMUM LOAD	9,961	17,329	14,102	12,743	14,783	15,888	19,426	19,651	15,137
TOP REACTION	1,732	3,036	2,452	2,216	2,571	2,763	3,379	3,418	......
TOP REACTION ADJUSTED TO 7-INCH DIAMETER	1,890	2,241	1,953	1,920	1,832	2,135	2,243	2,239	2,201
MODULUS OF RUPTURE	3,660	7,560	6,635	6,450	6,288	6,671	8,030	8,243	6,681

degree. The greatest stress developed in a pole in service is in the vicinity of the ground-line, where the defects are usually less marked than at the top. In poles of large taper, the point of failure is likely to be above the ground-line at a point where the pole diameter is 3/2 of the top diameter. Eastern cedar is a species in which the taper is pronounced.

To permit substitution of poles of the same strength but of different species, they are divided into seven strength classes as shown below:

Three other classes are recognized, 8, 9, and 10,

Class	Approximate Breaking Load
1	4,500 pounds
2	3,700 "
3	3,000 "
4	2,400 "
5	1,900 "
6	1,500 "
7	1,200 "

but no load requirements are specified; top dimensions are the criterion for these classes.

When the assigned minimum diameter for a pole of any species is computed, it is assumed that the load is applied two feet from the top of the pole and that the break occurs at the ground-line.

Tables of pole dimensions by species and classes are given in the Appendix.

The working stresses recommended by the Canadian Standards Association for certain species of timber which are used extensively for poles in Canada are as follows:

Species	Modulus of Rupture
	Lbs. per sq. in.
Eastern white cedar	3,600
Western red cedar	5,600
Douglas fir (creosoted)	8,400
Lodgepole pine (creosoted)	6,600
Jack pine (creosoted)	7,400
Red pine (creosoted)	6,600

Defects in Poles Used for Communications

Eastern white cedar poles are frequently subject to hollow heart and tunnelling by carpenter ants; other species may be affected with splinter-pulling caused during felling. These defective butts are permitted, provided the hollow heart does not exceed 10 per cent of the cross-section of the pole at the butt and does not extend more than 2 feet in depth.

Jack pine poles in particular and some other pole species are subject to attack by the fungus *Fomes pini*. This fungus first appears as a red-staining fungus which later develops white pockets in the heartwood of the pole. Tests on a large number of jack pine poles (19) have clearly indicated that, in the preliminary staining stage of infection, the fungus has no effect upon the strength of the pole. Development of the staining fungus to the pocket rot stage is accompanied by loss of strength. So long as the rotted area is near the neutral axis of the pole, where the stresses induced by bending are at a minimum, the effect of the rot is negligible. It was found that up to 20 per cent of rot near the centre of the pole had no appreciable effect upon the strength of the pole in bending.

The effect of fire-killing of poles has been investigated (21) and the results of tests indicate that fire-killed poles are as strong as those cut green, provided that the poles have not been attacked, subsequent to the fire, by fungus or insects.

Piling.—Commonly used species for piling are cedars, Douglas fir, larch, oaks, pines, spruces, and tamarack.

Piling timbers are generally classified according to the use intended:

(a) Piles for use in heavy railway bridges and trestles.

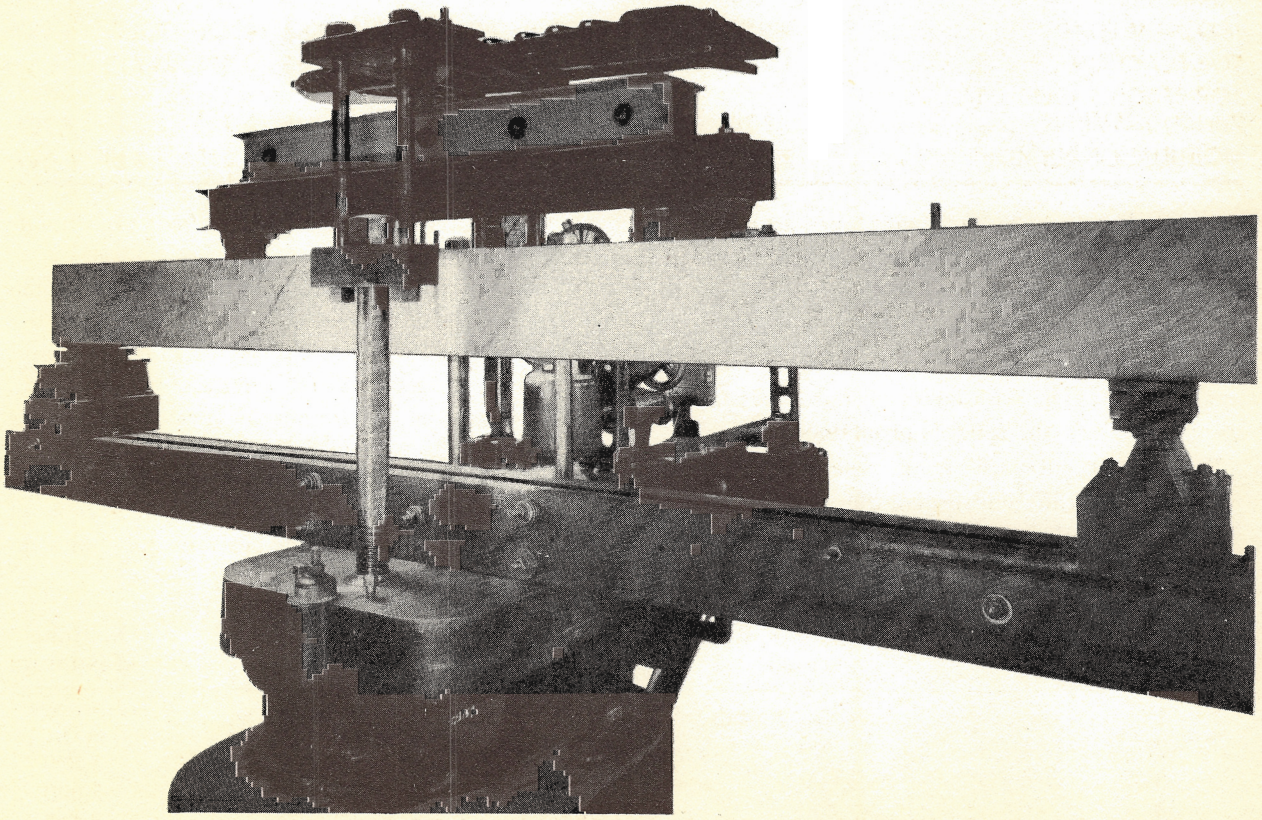


PLATE 49.—Plywood-web Box-beam Shown Under Bending Test.

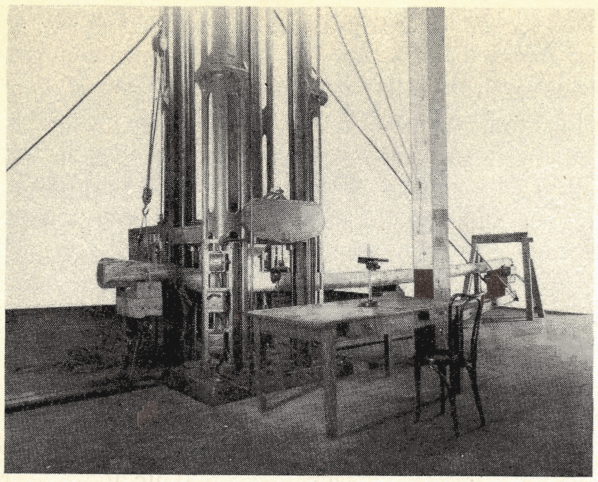


PLATE 50.—Testing Telephone Poles.

(b) Piles for use in docks, wharves, highway work, and general construction.

(c) Piles for use in foundations which will always be completely submerged, for coffer-dams, false-work, and sundry temporary work.

Complete specifications covering the sizes of wood piles designated under (a), (b), and (c) are contained in the Canadian Standards Association Specification A56-1942. This specification also describes defects permissible in satisfactory piling.

Ties

All commercial Canadian timbers have some value as railway tie material. The extent to which each species is used depends mainly upon its natural durability, treatability with preservatives, strength, availability, and cost. Natural durability is a property greatly desired for ties, but so few species are of themselves sufficiently resistant to decay that preservative treatment is now the rule for nearly all. Since, by modern methods of treating, practically all species can be sufficiently impregnated with preservatives to ensure comparative freedom from decay over long periods, the selection of suitable wood for tie material depends to a considerable extent upon its ability to stand up under the loads imposed upon it by the heavy rolling stock used by transportation companies.

A railway tie in service is subjected to a great variety of stresses, many of which are difficult to analyse. However, the mechanical suitability of a wood for railway ties may be measured by the resistance it offers to several of the more important of these stresses, such as *bending*, caused by loads on the rails near the ends of the ties; *compression perpendicular to grain*, tending to cause crushing under tie plates; *hardness* or ability to resist penetration of rock or gravel ballast.

Canadian timbers at present used for ties include eastern white cedar, eastern and western hemlock, tamarack, western larch, jack pine, Douglas fir, lodgepole pine, birch, beech, maple, and red and white oak. As will be noted, these woods cover a very wide range in so far as their strength properties are concerned. The woods most commonly used are those of fairly high mechanical properties such as birch, beech, maple, Douglas fir, western hemlock, western larch, jack pine, and lodgepole pine. These woods are usually subjected to preservative treatment before being placed in the line. The more durable of the softwoods are still used untreated in some branch lines.

As indicated in Chapter 6, "Decay and Stains in Wood", an investigation was carried out on jack pine ties affected with red rot and red stain to determine the effect of these two conditions upon their strength and spike-holding properties (30). The conclusions based on the tests are set forth in the chapter cited. An investigation carried out with respect to the effect of creosote treatment upon the strength of Douglas fir ties (16, 17) showed that the strength in resistance to crushing perpendicular to the grain was not impaired by the preservative treatment.

Top-pins

Wooden top-pins should be made from species that are strong and durable. Canadian woods which fulfil these requirements most satisfactorily are hard maple, yellow birch, beech, red oak, white ash, and white elm; of these, hard maple, yellow birch, and beech are the most favoured.

As the excellent qualities and the high mechanical strength of these Canadian woods are becoming better recognized, they are rapidly displacing imported species for top-pins. Untreated, these woods may not have the durability of some of the imported woods that have been used extensively, but by suitable treatment with preservatives the durability of top-pins made from these native species has been increased to such an extent that it compares very

favourably with that of the best imported woods used in their manufacture.

The following average values obtained from a large number of tests on 1½-inch diameter top-pins manufactured from the species mentioned indicate the suitability of these Canadian woods:—

Species	Average Load Sustained
	Lbs.
Hard maple	1,130
Yellow birch	1,060
Beech	1,060
Red oak	960
White ash	940
White elm	810

Cross-arms

The continued use of wood for cross-arms has been largely due to its non-conductivity, adaptability, strength, and durability.

Tests have been made at the Forest Products Laboratories on Douglas fir, red pine, and jack pine cross-arms. Of these three, Douglas fir has been found strongest, but both red pine and jack pine have adequate strength for cross-arm requirements. Douglas fir and red pine have also proved satisfactory in service tests. While service data are not yet available for jack pine, there is every indication that it will prove equally satisfactory.

As a result of a study of the effect of exposure on the strength of Douglas fir cross-arms (35), it was shown that the causes of loss of strength were abrasion and weathering. Tests showed that the wood at a short distance below the weathered surface of the cross-arm was unaffected by exposure.

One of the essential requirements for cross-arm material of good quality is freedom from defects in positions which would reduce its mechanical strength to any great extent. The most vital area is the vicinity of the point of support. As a consequence, defects in this area are of greater importance than those at points nearer the ends of the arm. The principal defects to be avoided in the choice of suitable material are large knots, cross-grain, deep checks, rot, and heavy wane.

Mine Timbers

Sawn, hewn, and round timbers are used in the shafts, galleries, drifts, stopes, and other parts of mines. The timbering in the shafts and main galleries is usually of a more or less permanent nature, while in drifts and stopes it is in many cases used for temporary support only. The conditions under which the timbers are used normally favour the quick development of decay, so that, if permanent support is required, timbers naturally resistant to decay or those treated with preservatives are preferred. In many mining operations, however, this is not economically feasible. The majority of Canadian mines are located in sections of the country where an abundance of timber is available, and it has, therefore, been customary to utilize local species. In various localities we find in use such timbers as jack pine, spruce, white and yellow birch, white and rock elm, hard maple, balsam fir, eastern hemlock, tamarack, eastern white cedar, lodgepole pine, Douglas fir, western red cedar, and western hemlock.

The loads that the timbers have to support are for the most part undeterminable, but they are in many cases sufficiently great to stress the timber beyond the limits of safety. Where timbers are so stressed they will ultimately fail, so that when timbers available locally are used, it may be necessary to carry out renewals at shorter intervals than for stronger timbers brought in from outside districts. As two or more species suitable for use as mine timber are usually available in the vicinity of the mine, the selection should, in most cases, be made on the basis of strength and durability.

Conditions of safety make it desirable that a mine timber should give warning of impending failure, either by audible cracking or by excessive deflection, thus indicating the urgency of replacing or reinforcing the timber. "Reserve strength" of a species, therefore, should be taken into consideration when determining its suitability for mine timber.

IMPROVED WOOD

In addition to the preservative treatment of wood, to render it resistant to decay and the attacks of borers, much investigation has been undertaken with a view to improving the natural properties of wood. Stabilization of wood, by reduction in its capacity to swell or shrink with changes in moisture content, has been one aspect which has received considerable attention, and some success has been attained.

Stabilization has been obtained to a greater or lesser extent by the application of heat, of pressure,

of combinations of heat and pressure, and by the use of chemicals.

It is difficult to obtain complete and uniform penetration of chemical solutions into thick pieces of wood. In the preparation of improved wood, it is customary to use only thin sheets or veneers which are soaked or dipped in solutions of resinoids—particularly aqueous phenolformaldehyde resin-forming solutions—and subsequently dried; these are then assembled into the required thickness and bonded by curing or setting the resin under the normal pressures used in plywood manufacture. Use of thick wood in this process requires either long periods of soaking, or pressure treatment, in order to obtain uniform penetration by the resin-forming chemicals, which are subsequently converted into insoluble resins by the application of heat. The resulting product is known by the generic term "impreg"—a contraction of "impregnated".

If, during the curing of the resin, considerable pressure (up to 1,500 pounds per square inch) is applied to the wood, the density of the product and many of its strength characteristics are increased. The resulting product may have a density as high as 1.3, but is frequently compressed to a lesser degree, with intermediate density, for special applications.

The term "Compreg" has been generally applied to this type of resin-impregnated compressed wood, though many trade names more or less descriptive of the material have been used.

The properties of impreg may be more desirable than those of untreated wood, in that the tendency to change dimensions in response to fluctuating humidity is decreased. The specific gravity, hardness, and certain mechanical properties, as well as resistance to decay and attack by wood borers, is increased. Compreg has these qualities in even greater measure, their increase depending in some degree upon the amount the wood has been compressed, and the amount and composition of resin-forming materials present.

As compreg, with a maximum of dimensional stability and of high density and hardness, can be produced from relatively inferior woods such as poplar, the advantages of the process will be apparent.

Compreg has been used for the manufacture of many specialized products such as knife handles, picker sticks, shuttle blocks, propeller blades for aircraft, rubbing strakes for boats, and reinforcing plates for aircraft spars. Its strength and lightness, and the ease with which it can be worked have proved compreg to be a very useful substitute for metal dies for press work, and its use for this purpose was greatly increased in production of munitions during the war.

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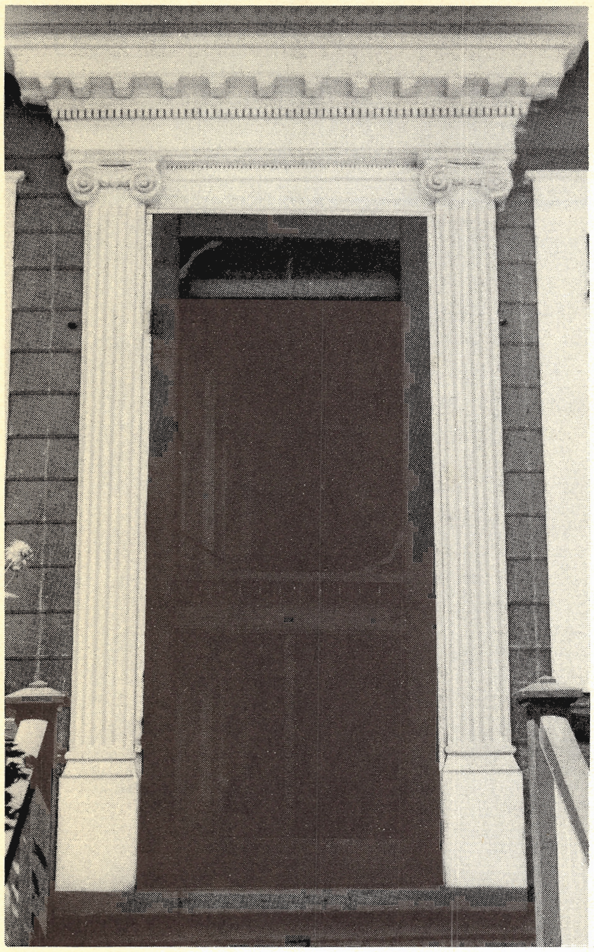
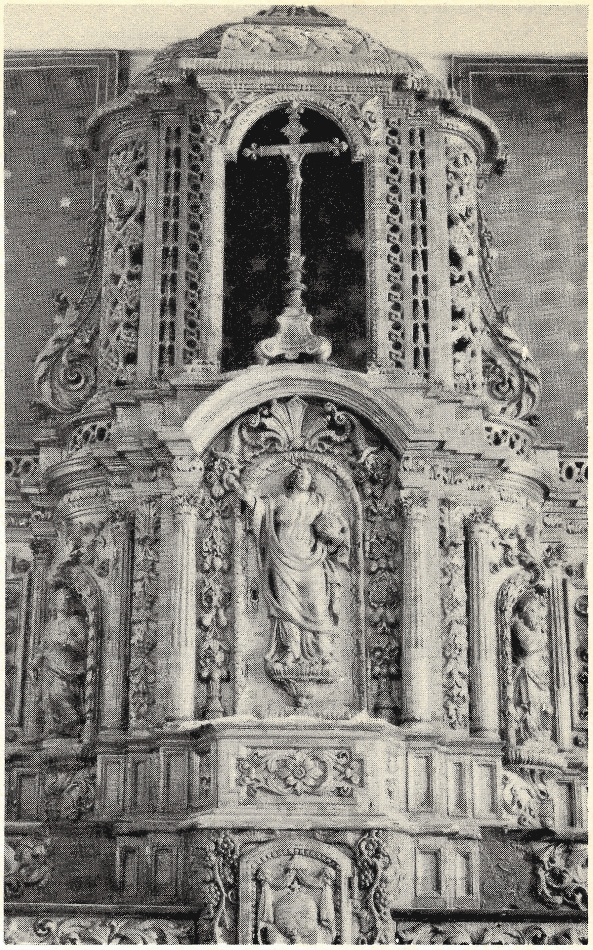




(*Left*). Doorway, Ile d'Orléans, Quebec. (*Right*). This Tabernacle at Longueuil, Quebec, well exemplifies the high degree of skill developed by the wood carvers of the Cap Tourmente School, founded by Bishop Laval.

The strictly functional approach shown in this barn has its inherent beauty.

CONTRASTS IN WOOD CONSTRUCTION.

CHAPTER 5

THE SEASONING OF LUMBER

by R. S. MILLETT*

PURPOSE OF SEASONING LUMBER

GREEN lumber, when first sawn from the log, contains a large proportion of water, which renders it unfit for immediate commercial use for most purposes. The process of removing the desired amount of this moisture to render the lumber suitable for various purposes is known as seasoning, curing, or conditioning.

Seasoning is the last process in the manufacture of rough lumber, and the first process in the manufacture of dressed lumber or lumber products. It is properly considered one of the most important processes in lumber manufacture. Carelessness at this stage may make subsequent manufacture unsatisfactory and often results in failure while the product is being used.

When wood is exposed to specific conditions of temperature and relative humidity for some time, it will acquire a moisture content consistent with those conditions. As it shrinks when dried below the fibre saturation point, which occurs at a moisture content of approximately 25 per cent, it should be dried to the equilibrium moisture content which it would acquire in service, thus reducing the amount of shrinkage and the possibility of splitting after manufacture. Stain and decay will not occur in lumber which has been seasoned to a moisture content of less than 20 per cent unless it is again exposed to moist conditions. It is also necessary to season lumber to reduce its shipping weight and to improve its manufacturing and painting qualities.

*In bringing this Chapter up to date, extensive use has been made of the original material prepared by Mr. W. J. Leclair for the first edition.

MOISTURE IN WOOD

Forms of Moisture in Wood

Moisture is present in wood in two forms, which may be termed "hygroscopic" and "free". To understand the meaning of these two terms, one must visualize the substance, wood, as being similar to a honeycomb or sponge, the individual hollow fibres of wood corresponding to the cavities or the cells of the sponge. The water held in the material composing the cell-walls is termed "hygroscopic", that occupying the hollow spaces between the walls is known as "free".

When wood dries, the "free" water evaporates first, followed by the "hygroscopic" water. The condition existing when all the free water has been evaporated and the cell-walls are still saturated is known as the "fibre saturation point" and usually occurs when the wood reaches a moisture content of around 25 per cent of the oven-dry weight, varying somewhat with different species.

Lumber green from the saw has the same moisture content as the log from which it is sawed. This will depend on the species, the method and duration of transportation and storage previous to sawing, and the proportions of heartwood and sapwood. The

moisture content of green lumber may vary from around 40 per cent in the heartwood of Douglas fir to from 100 to 200 per cent in the sapwood of white pine and hemlock.

Moisture Content

The moisture content of wood is generally expressed as a percentage of the oven-dry weight of the wood and may be determined in the following manner.

Oven-dry Method

1. To prepare test pieces for determination of average moisture content and moisture distribution, cut one or more sections the full width of the board and one-half to three-quarters of an inch along the grain, as illustrated in Figure 14. Since wood dries more quickly along the grain than across it, the sections should be cut at least 2 feet from the end of the board, to eliminate any portion in which end-drying may have occurred. Sections should not be cut near knots, rot, pitch streaks, or other abnormalities, where the moisture content may not be truly representative of that of the whole board.

2. Trim all loose slivers from the sections and weigh the latter immediately as accurately as possible: the result is called the "original weight". If a small-capacity scale is not available, a number of thin sections may be cut and bundled together and weighed as a unit. When cutting thin sections, care must be taken that the saw is sharp, lest it burn the wood and dry it prematurely.

3. Place the sections in an oven heated to 212°F. (100°C.), and allow them to remain there until all the moisture has been removed. The length of time required for this depends on the size and moisture content of the section. Twelve to eighteen hours is usually sufficient for small sections cut from kiln-dried lumber.

4. When the sections have reached a constant weight, i.e., when all the moisture has been evaporated, remove them from the oven and weigh them accurately: the result is called the "oven-dry weight". It is necessary that the weighings be done while the sections are still warm, as they begin to absorb moisture from the air as soon as they are cool.

5. The moisture content, based on the oven-dry weight, may be calculated from the following formula:

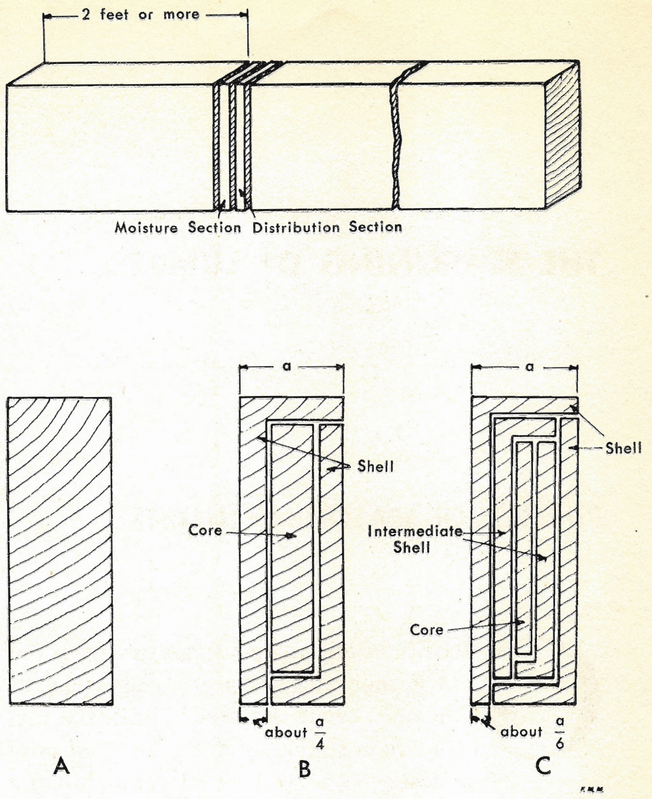


FIGURE 14.—Method of Cutting Test Sections for Moisture Determination.

Moisture content, per cent =

$$\frac{\text{Original Weight} - \text{Oven-dry Weight}}{\text{Oven-dry Weight}} \times 100$$

The following is an example of the oven-dry method of determining the moisture content of wood.

Original weight of section = 90.00 grams

Oven-dry weight of section = 75.00 grams

$$\text{Moisture content} = \left(\frac{90.00 - 75.00}{75.00}\right) \times 100 = 20 \text{ per cent}$$

Sensitive equipment is necessary to obtain accurate results. A triple-beam balance, graduated to .01 gram, and an electric oven, thermostatically controlled, have proved very satisfactory for this purpose.

Electric Moisture Meter Method

Another method of determining the moisture content of wood is the electric moisture meter method, which takes advantage of the fact that resistance to an electric current passing through wood varies with the moisture content. This is a

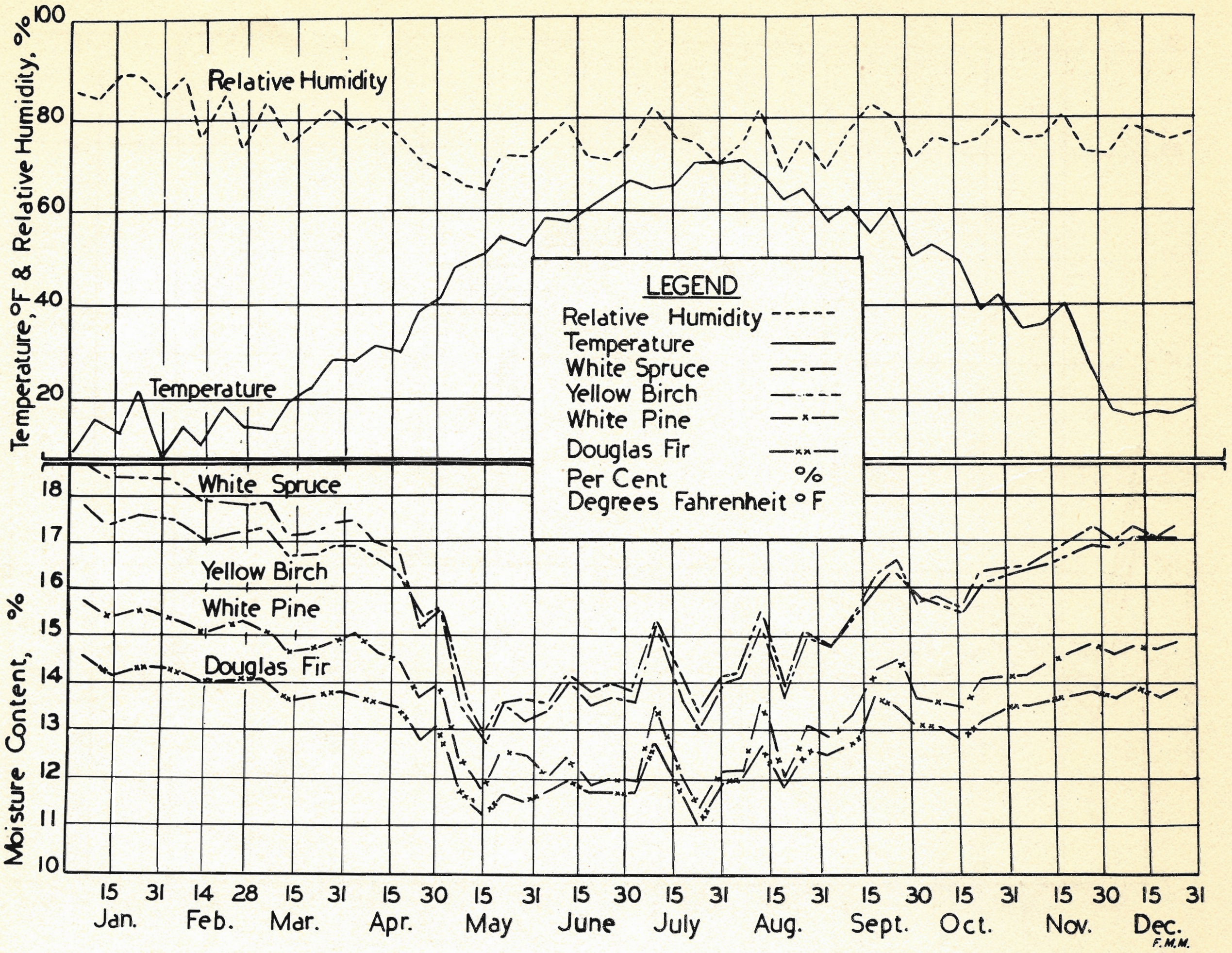


FIGURE 15.—Equilibrium Moisture Content of Lumber Exposed to Outdoor Conditions at Montreal.

quick method of determining moisture content and is reasonably accurate for those between 6 and 25 per cent, but must not be expected to replace the oven-dry method in following the moisture content of a charge of lumber being kiln-dried. Best results are obtained on lumber not exceeding 2 inches in thickness.

EQUILIBRIUM MOISTURE CONTENT

Wood is a hygroscopic substance, i.e. it is very sensitive to changes in moisture content of the surrounding atmosphere, and if left exposed to air at specific conditions of temperature and relative humidity it will eventually acquire a moisture content which depends on these conditions. This moisture content balance of wood with the surrounding atmospheric conditions is known as its equilibrium moisture content. It will, therefore, be obvious that wood should be seasoned previous to manufacture to within the equilibrium moisture content range which the finished product will acquire during use.

Equilibrium Moisture Content of Wood in Canada

Figure 15 illustrates the equilibrium moisture content of one-inch material, computed from data collected from weekly tests of various species at Montreal, P.Q. All samples were thoroughly air-dry at the commencement of the study. They were piled in an open shed, where they had contact with outside air conditions but were protected from rain and snow. The results of the tests may also be taken as

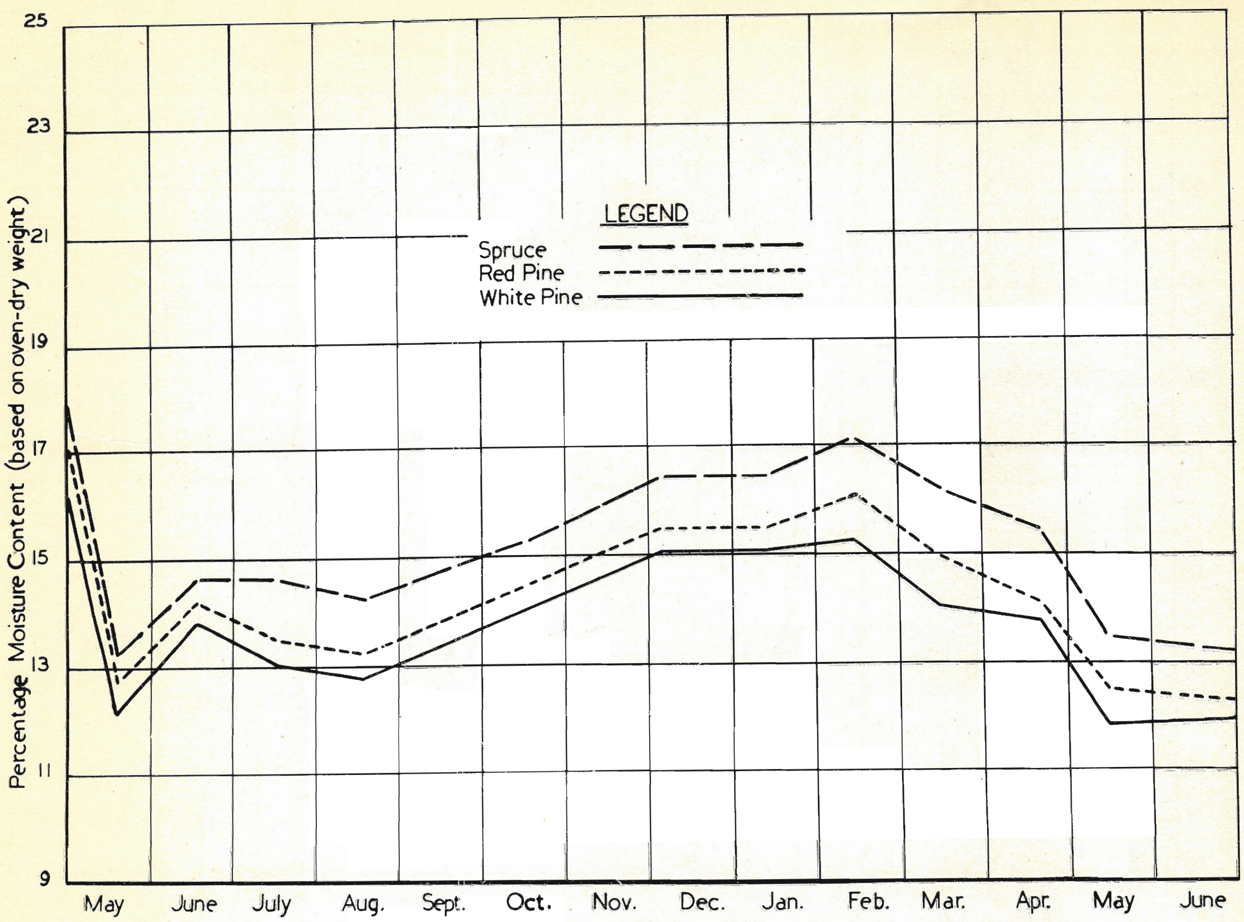


FIGURE 16.—Equilibrium Moisture Content of Lumber Exposed to Outdoor Conditions in the Ottawa Valley.

representative of the equilibrium moisture content of the lumber of other species when stored in the Montreal district.

Figure 16 illustrates the equilibrium moisture content of 1″ by 6″ by 14′/16′ lumber in actual piles in a commercial yard in Ottawa. These values may be considered as indicative of conditions in the Ottawa Valley.

Air-seasoning studies conducted in the southern coast region of British Columbia showed minimum average moisture contents of between 13.0 and 13.4 per cent for thoroughly air-seasoned one-inch Douglas fir, western hemlock, and Sitka spruce lumber in the summer, with moisture pick-up during the fall and winter until an equilibrium moisture content of 22 per cent was reached during December and January.

Equilibrium Moisture Content of Wood in England

The Forest Products Research Laboratory at Princes Risborough, England, conducted tests on samples of oak, mahogany, and Scots pine over a period of two years in five representative localities in England. The average results of these tests are summarized in Table 13.

Equilibrium Moisture Content of Wood in the United States

In the United States, the equilibrium moisture content varies with different localities. Table 14 shows the estimated average moisture content of interior woodwork in different cities during the months of July and January.*

*Peck, E. C. Moisture Content of Wood in Dwellings, U.S. Dept. of Agr., Madison, Wis., Forest Service Circ. 239, 1932.

TABLE 13

EQUILIBRIUM MOISTURE CONTENT OF WOOD IN ENGLAND

WHERE USED	MOISTURE CONTENT		
	Lowest	Highest	Average
	P.C.	P.C.	P.C.
Outdoors	14	18	16
Indoors			
Offices	10	13	11.5
Living rooms	11	13	12
Bedrooms	12	14	13

TABLE 14

ESTIMATED AVERAGE MOISTURE CONTENT OF INTERIOR WOODWORK IN DIFFERENT CITIES DURING JULY AND JANUARY

CITY	MOISTURE CONTENT	
	July	January
	P.C.	P.C.
Duluth, Minn.	10.5	5.0
Madison, Wis.	10.0	6.0
Boston, Mass.	13.0	7.0
New York, N.Y.	12.5	7.0
Washington, D.C.	11.0	8.0
Atlanta, Ga.	11.5	8.5
New Orleans, La.	13.5	12.5
Dallas, Texas	9.0	9.0
Albuquerque, New Mexico	6.0	7.0
Salt Lake City, Utah	4.0	7.0
San Francisco, Cal.	10.5	10.5
Portland, Oregon	9.5	9.0
Seattle, Wash.	11.0	8.5

Moisture Content of Lumber for Various Uses

In deciding upon a proper moisture content to which lumber should be dried for a particular use, consideration should be given to the atmospheric conditions to which the lumber or article will be exposed when in use. These will vary according to the locality and the season of the year.

In Canada, it is usual to select wood with a moisture content of between 12 per cent and 18 per cent for the manufacture of articles destined for outdoor use, and a moisture content of between 5 per cent and 10 per cent for articles which will be used indoors. It is obviously difficult to generalize in this matter, since conditions of use are so varied. That moisture content which appears to be most suitable for the specific conditions under which the manufactured article will be used must therefore be adopted. For instance, for certain uses in connection with harbour and river construction work, green or almost green timber may be used. On the other hand, when making glued joints with vegetable glue, a moisture content as low as 3 per cent may be satisfactory.

HOW WOOD DRIES

Theory of Lumber Seasoning

Wood is dried by evaporation of the contained water. The moisture on the surface of lumber is picked up by the surrounding air in the form of water vapour. When this occurs, the moisture from the zone immediately beneath the surface moves to the drier surface zone and sets up a moisture flow between the interior and the surface. This continues successively until the whole interior gives up its surplus moisture. It is not clearly understood whether this moisture movement is caused by a difference in vapour pressure or by diffusion. It is possibly caused by a combination of both, but it is known that the movement is most rapid towards end surfaces. The movement towards the tangential (flat-grained) surfaces is generally considered to be more rapid than that towards the radial (edge-grained) surfaces.

A controlling factor in all drying is the rate at which the surface moisture is picked up by the surrounding air. This in turn is influenced by relative humidity, temperature, and circulation. There is no basic difference in principle between air-seasoning and kiln-drying.

TABLE 15

MOISTURE-HOLDING CAPACITY OF AIR

Temperature		Weight of Moisture at Saturation	
	60	5.8	
	80	11.1	
Degrees	100	20.0	Grains
Fahrenheit	120	34.4	per
	140	56.9	cu. ft.
	160	90.6	
	180	139.4	

Relative Humidity and its Measurement

The amount of moisture in the air may be expressed in grains per cubic foot of air, or as relative humidity. Table 15 lists the maximum amount of moisture which a cubic foot of air will hold at various temperatures.

Air has reached the saturation point when it has lost its capacity to take up further moisture unless the temperature is increased. Saturated air has no drying power, as air can only dry materials by picking up additional moisture from them. To express the drying power of air, the term "relative humidity" is used. By this term is meant the actual amount of water vapour in air expressed as a percentage of the total amount it would hold at saturation without change of temperature. Referring to Table 15, air which contains 5.8 grains of moisture at 60°F. is saturated, or has a relative humidity of 100 per cent. When heated to a temperature of 100°F. without any change in total moisture content, the relative humidity changes to:

$$\frac{5.8 \times 100}{20.0} = 29 \text{ per cent}$$

In general, other factors being constant, the lower the relative humidity the faster the rate of surface evaporation, and vice versa. If the movement of moisture from the interior could be depended on to take place as rapidly as evaporation from the surface, drying would be a simple process. Unfortunately, this is not the case.

The method of measuring the relative humidity is by means of a hygrometer, which consists of two adjacent thermometers, the bulb of one being dry, while the bulb of the other is maintained in a moist condition, usually by means of a wick or porous sleeve surrounding it and fed from a reservoir of water. From the difference between the temperatures of the wet and dry bulbs, the relative humidity is computed, and hygrometric tables or graphs are published from which the relative humidity conditions may be read directly for the wet bulb and dry bulb temperatures which have been determined by the hygrometer.

Table 16 shows the relative humidity of air at different temperatures of the wet and dry bulbs, also the equilibrium moisture content of wood under specific conditions of temperature and relative humidity.

There must be a close relationship between the rate of surface evaporation and the rate at which the moisture transfuses from the interior to the surface of the wood. In the resultant drying, the "free" water in wood must be removed before the moisture content of the cell-walls can be reduced. To effect this, the drying of the surface of the lumber must be regulated to the rate of transfer of moisture from the interior, otherwise the shrinkage of the shell over the core, in which shrinking has not commenced, will set up strains in the lumber; this may cause checking, warping, or honeycombing, and a consequent de-grading of lumber. Not only does too rapid drying of the surface cause seasoning de-grade, but it may actually slow the drying process.

LUMBER SEASONING PRACTICE

Methods of Seasoning

Lumber is generally seasoned by either air-seasoning or kiln-drying.

Air-seasoning is the process of removing moisture from wood by exposing it to atmospheric conditions. Ordinarily, the lumber is flat-piled in open yards with crossers between courses, but sometimes it is edge-piled. Occasionally it is end-racked in specially constructed sheds. In all instances, provision is made for a circulation of air around the individual pieces.

Dry-kiln seasoning is a process of removing moisture from wood by the use of artificial heat. The term 'kiln-dried' is sometimes used as if to indicate a *degree* of seasoning. This is not correct; the term should only be used to indicate the *process* of seasoning, as the kiln-drying of a charge of lumber may be stopped at any time to provide a specified degree of seasoning (or mosture content).

Advantages and Disadvantages

Air-seasoning does not require a large initial outlay for buildings and equipment, but requires lumber to be held in yard storage for a long time before it is ready for market. In contrast, dry-kiln seasoning requires a comparatively large capital investment, but dries the lumber in a short time, with resultant quick turn-over of stock. In Canada, dry-kilns are necessary in drying lumber for purposes where low moisture contents are required. They also provide dry lumber at all seasons of the year.

AIR-SEASONING

Yard Location and Lay-out

Numerous factors (such as fire underwriters' regulations, cost of land, and convenience of shipping) usually enter into the selection of air-seasoning yards; these, though not directly relevant to seasoning, are of major importance. As a result, a compromise is often necessary between the selection of an adequate site and one which will provide cramped piling facilities. Too often, however, the tendency is to give considerable thought to mill location and too little to yard location.

A yard site should be well drained, and preferably have a mineral soil. It should be convenient to the sawmill, the planing mill, and shipping facilities, and should be laid out so that the direction of lumber travel is, as far as possible, in one direction from the sawmill to the railway siding. It should be compact, in order to keep costs to a minimum, but should be sufficiently large to render high piling unnecessary, as this practice is costly and is not conducive to uniform drying. High piling is justified only where the cost of land is such as to render it necessary for economic reasons.

The yard layout is very important in providing satisfactory air-seasoning of the lumber. The roads, streets, or alleys in lumber yards should be as straight as possible. Where space is available, they should be wide enough to provide good air circulation at both the front and rear. The spaces between the piles should also be ample for the same reason. Where space is limited and the piles have to be placed close together, care should be taken that the roads run in the same direction as the prevailing wind.

Piling Methods

Green lumber piled outdoors to season by exposure to the atmosphere is frequently found to suffer severe checking and warping—a state of affairs usually blamed on weather conditions, but actually the result of poor piling practice.

As a matter of fact, quite as much technique is required to air-season lumber properly as to kiln-dry it. In both instances the principle of drying—that is, by evaporation—is the same. The same three drying agents—heat, humidity, and circulation—are employed in both. In air-seasoning, however, one has a measure of control over circulation only, and such regulation of temperature and relative humidity as is possible is effected by increasing or restricting circulation by means of piling methods.

No particular method or style of piling can be advised as a general rule, because there are too many varying factors which must be considered. In no two yards are conditions identical. In one yard, stain may be the chief de-grading factor, while checking may be the most detrimental in another. In yard practice, stain is generally guarded against by piling so as to increase the circulation and thus reduce the drying period, but that practice, if carried to extremes, may cause serious checking.

The logical procedure would be to effect a compromise between the occurrence of stain and checking by piling, in such way as to eliminate or reduce stain and at the same time produce straight lumber, with checking and cupping held to a minimum.

The following are suggested as proper practice in preparing pile foundations and in piling.

1. The use of solid and strong foundations with sufficient bearing surface to remain in place is very important. If the foundations sink or tip, the lumber will sag a corresponding amount and will warp and split, producing de-grade of varying degrees. To assist in reducing this danger, the foundations should not be placed on swampy or filled-in ground where frost action is likely to be severe, unless this ground has previously been well drained and compacted. Concrete foundations are advised where the yard site will be permanent. Any suitable timbers may be used where a lumber yard will only be in existence a few years. These should be treated with some form of preservative to prevent decay which might, in turn, infect the fresh lumber. The foundations should preferably be built in pier form, so that circulation will not be cut off in either the longitudinal or transverse direction of the pile. This method is shown in Figure 17.

2. The height of foundations should not be less than 1½ feet at the rear and should be high enough at the front to provide a slope from the front to the back of the pile of approximately 1 in 12, as shown in Figure 17.

3. The foundation piers should be longitudinally and transversely spaced 4 feet apart to provide piling facilities for 16-foot lumber and for a pile 8 to 12 feet wide so that short, narrow lengths of the lumber being piled may be used for crossers.

RELATIVE HUMIDITY AND APPROXIMATE EQUILIBRIUM MOISTURE CONTENT OF WOOD

DIFFERENCE BETWEEN READINGS OF WET AND DRY BULBS IN DEGREES FAHRENHEIT

TABLE 16

Dry Bulb °F	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17	
	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC
30	89	23.5	78	18.3	67	14.4	56	11.9	46	10.3	36	8.4	26	7.0	16	5.3	6	3.4																
35	91	24.5	81	19.5	72	15.6	63	13.2	54	11.3	45	9.8	36	8.4	27	6.9	19	5.6	10	4.0	2	—												
40	92	25.0	83	20.2	75	16.6	68	14.3	60	12.4	52	10.8	45	9.7	37	8.3	29	7.2	22	5.9	15	4.8	7	3.3										
45	93	25.5	86	21.3	78	17.6	71	14.9	64	13.0	57	11.7	51	10.6	44	9.3	38	8.3	31	7.3	25	6.3	18	5.2	12	4.1	6	2.9						
50	93	25.3	87	21.5	80	18.2	74	15.6	67	13.6	61	12.3	55	11.1	49	10.1	43	9.0	38	8.2	32	7.3	27	6.4	21	5.4	16	4.7	10	3.5	5	1.1		
55	94	25.9	88	21.9	82	18.9	76	16.2	70	14.3	65	12.9	59	11.8	54	10.8	49	9.9	43	8.8	38	8.1	33	7.3	28	6.4	23	5.6	19	4.9	14	4.2	9	3.3
60	94	25.8	89	22.2	83	19.0	78	17.0	73	15.0	68	13.5	63	12.4	58	11.3	53	10.5	48	9.6	43	8.6	39	8.1	34	7.3	30	6.5	26	5.8	21	5.2	17	4.4
65	95	26.4	90	22.6	85	20.0	80	17.5	75	15.4	70	13.9	66	12.8	61	11.9	56	10.8	52	10.2	48	9.4	44	8.6	39	7.9	35	7.2	31	6.5	27	5.9	24	5.4
70	95	26.2	90	22.5	86	20.3	81	17.8	77	15.9	72	14.3	68	13.2	64	12.3	59	11.2	55	10.5	51	9.8	48	9.2	44	8.5	40	7.9	36	7.2	33	6.7	29	6.0
75	96	26.7	91	23.0	86	20.0	82	17.9	78	16.0	74	14.6	70	13.5	66	12.6	62	11.7	58	10.8	54	10.2	51	9.6	47	8.8	44	8.4	40	7.7	37	7.2	34	6.7
80	96	26.6	91	22.8	87	20.3	83	18.0	79	16.2	75	14.8	72	13.9	68	12.9	64	12.0	61	11.3	57	10.5	54	10.0	50	9.2	47	8.7	44	8.2	41	7.7	38	7.2
85	96	26.5	92	23.4	88	20.5	84	18.2	80	16.5	76	14.9	73	14.0	70	13.3	66	12.3	63	11.5	59	10.8	56	10.2	53	9.6	50	9.0	47	8.5	44	8.0	41	7.5
90	96	26.5	92	23.0	89	20.9	85	18.5	81	16.6	78	15.4	74	14.1	71	13.3	68	12.5	65	11.8	61	10.9	58	10.4	55	9.8	52	9.2	49	8.7	47	8.4	44	7.8
95	96	26.4	93	23.6	89	20.5	85	18.4	82	17.0	79	15.5	75	14.2	72	13.4	69	12.6	66	11.9	63	11.2	60	10.7	57	10.0	54	9.4	52	9.0	49	8.5	46	8.0
100	96	26.2	93	23.5	89	20.4	86	18.5	83	17.1	80	15.6	77	14.6	73	13.4	70	12.7	68	12.2	65	11.4	62	10.8	59	10.2	56	9.6	54	9.3	51	8.7	49	8.4
102	96	26.1	93	23.4	89	20.2	86	18.3	83	17.0	80	15.5	77	14.5	74	13.7	71	12.8	69	12.4	65	11.4	62	10.8	59	10.2	57	9.8	54	9.1	52	8.8	49	8.3
104	96	26.0	93	23.2	90	20.8	86	18.2	83	16.9	80	15.4	77	14.4	74	13.6	71	12.8	69	12.3	65	11.3	63	10.9	60	10.3	58	9.9	55	9.3	52	8.7	50	8.4
106	96	25.9	93	23.0	90	20.6	87	18.6	83	16.6	80	15.3	77	14.4	74	13.5	72	12.9	-69	12.2	66	11.5	63	10.8	60	10.2	58	9.8	56	9.4	53	8.8	51	8.4
108	96	25.8	93	22.9	90	20.5	87	18.5	84	17.1	81	15.6	78	14.6	75	13.7	72	12.8	70	12.4	66	11.4	64	10.9	61	10.4	59	9.9	56	9.3	54	8.9	51	8.4
110	96	25.8	93	22.8	90	20.5	87	18.4	84	17.0	81	15.5	78	14.5	75	13.7	72	12.8	70	12.3	67	11.6	64	10.8	62	10.5	60	10.1	57	9.5	55	9.1	52	8.5
112	96	25.7	93	22.7	90	20.3	87	18.2	84	16.9	81	15.5	78	14.4	75	13.6	73	13.0	70	12.3	67	11.5	65	11.0	62	10.4	60	10.0	57	9.4	55	8.9	53	8.6
114	97	26.5	93	22.6	90	20.0	87	18.1	84	16.7	81	15.4	78	14.4	75	13.5	73	12.9	71	12.4	68	11.8	65	10.9	63	10.5	61	10.2	58	9.5	56	9.1	53	8.5
116	97	26.5	93	22.5	90	20.0	88	18.6	84	16.6	82	15.6	79	14.6	76	13.7	74	13.1	71	12.3	68	11.7	66	11.1	63	10.4	61	10.1	59	9.6	56	9.0	54	8.7
118	97	26.4	93	22.4	91	20.6	88	18.5	85	17.1	82	15.5	79	14.5	76	13.6	74	13.0	71	12.3	68	11.5	66	11.0	64	10.6	62	10.2	59	9.6	57	9.2	54	8.6
120	97	26.3	94	23.5	91	20.5	88	18.4	85	17.0	82	15.4	79	14.4	77	13.8	74	12.9	72	12.4	69	11.8	66	10.9	64	10.5	62	10.1	60	9.7	57	9.1	55	8.7
122	97	26.3	94	23.0	91	20.2	88	18.3	85	16.9	82	15.3	79	14.3	77	13.8	75	13.2	72	12.4	69	11.7	67	11.1	65	10.6	63	10.2	60	9.7	58	9.2	56	8.8
124	97	26.2	94	22.9	91	20.0	88	18.2	85	16.8	83	15.6	80	14.6	77	13.7	75	13.0	72	12.3	70	11.8	67	11.0	65	10.6	63	10.1	61	9.8	58	9.1	56	8.7
126	97	26.2	94	22.8	91	20.0	88	18.0	86	17.1	83	15.5	80	14.5	78	13.9	75	12.9	73	12.5	70	11.8	68	11.2	65	10.5	64	10.3	61	9.7	59	9.3	57	8.8
128	97	26.1	94	22.6	91	19.9	89	18.5	86	17.0	83	15.4	80	14.4	78	13.8	76	13.2	73	12.4	71	11.9	68	11.1	66	10.7	64	10.2	61	9.6	59	9.2	57	8.8
130	97	26.0	94	22.5	91	19.7	89	18.3	86	16.9	83	15.3	80	14.3	78	13.8	76	13.1	73	12.4	71	11.8	68	11.0	66	10.6	64	10.1	62	9.8	60	9.3	58	8.9
132	97	26.0	94	22.3	92	20.5	89	18.1	86	16.7	83	15.2	81	14.5	78	13.7	76	13.0	74	12.5	71	11.7	69	11.2	67	10.8	65	10.3	62	9.7	60	9.3	58	8.8
134	97	25.9	94	22.1	92	20.0	89	18.0	86	16.5	84	15.5	81	14.5	79	13.9	76	13.0	74	12.4	71	11.6	69	11.1	67	10.7	65	10.2	63	9.8	61	9.4	59	8.9
136	97	25.8	94	22.0	92	20.0	89	18.0	86	16.4	84	15.4	81	14.4	79	13.8	77	13.2	74	12.4	72	11.9	69	11.0	67	10.6	65	10.1	63	9.7	61	9.3	59	8.8
138	97	25.7	94	21.9	92	19.8	89	17.9	86	16.2	84	15.3	81	14.3	79	13.7	77	13.1	74	12.3	72	11.8	70	11.2	68	10.8	66	10.3	63	9.6	62	9.4	60	9.0
140	97	25.6	94	21.8	92	19.5	89	17.7	87	16.7	84	15.2	81	14.3	79	13.6	77	13.0	75	12.5	72	11.7	70	11.1	68	10.7	66	10.2	64	9.8	62	9.3	60	8.9
142	97	25.5	94	21.7	92	19.4	89	17.6	87	16.5	84	15.1	82	14.5	80	13.9	77	12.9	75	12.4	73	11.9	70	11.0	68	10.6	66	10.1	64	9.7	62	9.3	60	8.8
144	97	25.4	95	22.4	92	19.2	89	17.5	87	16.4	84	15.0	82	14.4	80	13.8	78	13.2	75	12.3	73	11.8	71	11.1	69	10.8	67	10.3	65	9.8	63	9.4	61	9.0
146	97	25.3	95	22.2	92	19.0	90	18.0	87	16.3	85	15.3	82	14.3	80	13.7	78	13.1	75	12.3	73	11.7	71	11.0	69	10.7	67	10.2	65	9.7	63	9.3	61	8.9
148	97	25.2	95	22.0	92	19.0	90	17.9	87	16.1	85	15.2	82	14.3	80	13.6	78	13.0	76	12.4	73	11.6	71	11.0	69	10.6	67	10.1	65	9.6	63	9.2	61	8.8
150	98	26.4	95	21.9	92	18.8	90	17.7	87	16.0	85	15.1	82	14.2	80	13.5	78	12.9	76	12.3	74	11.8	72	11.2	70	10.7	68	10.2	66	9.8	64	9.4	62	8.9
152	98	26.3	95	21.7	93	19.5	90	17.6	88	16.5	85	15.0	83	14.4	81	13.8	79	13.1	76	12.3	74	11.8	72	11.1	70	10.6	68	10.2	66	9.7	64	9.3	62	8.8
154	98	26.2	95	21.6	93	19.0	90	17.5	88	16.4	85	14.9	83	14.3	81	13.7	79	13.0	77	12.5	74	11.7	72	11.0	70	10.5	68	10.1	66	9.6	65	9.4	63	9.0
156	98	26.1	95	21.5	93	19.0	90	17.3	88	16.2	85	14.8	83	14.3	81	13.6	79	12.9	77	12.4	74	11.5	72	10.9	71	10.7	69	10.2	67	9.8	65	9.3	63	8.9
158	98	26.0	95	21.4	93	18.9	90	17.2	88	16.1	86	15.0	83	14.2	81	13.5	79	12.9	77	12.3	75	11.8	73	11.1	71	10.6	69	10.2	67	9.7	65	9.2	63	8.8
160	98	25.9	95	21.2	93	18.7	90	17.1	88	16.0	86	15.0	83	14.1	81	13.4	79	12.8	77	12.3	75	11.7	73	11.0	71	10.5	69	10.1	67	9.6	65	9.2	64	8.9
162	98	25.8	95	21.0	93	18.6	90	17.0	88	15.9	86	14.9	84	14.3	82	13.7	80	13.0	77	12.2	75	11.5	73	10.9	71	10.4	69	10.0	68	9.8	66	9.3	64	8.8
164	98	25.6	95	20.5	93	18.5	91	17.5	88	15.7	86	14.8	84	14.3	82	13.6	80	12.9	78	12.4	75	11.4	73	10.8	72	10.6	70	10.1	68	9.7	66	9.2	64	8.8
166	98	25.4	95	20.0	93	18.5	91	17.3	88	15.6	86	14.8	84	14.2	82	13.5	80	12.9	78	12.3	76	11.6	74	11.0	72	10.5	70	16.0	68	9.6	66	9.1	65	8.9
168	98	25.2	95	19.8	93	18.3	91	17.2	88	15.5	86	14.7	84	14.1	82	13.4	80	12.8	78	12.2	76	11.5	74	10.9	72	10.4	70	9.9	68	9.5	67	9.3	65	8.8
170	98	25.1	95	19.5	93	18.2	91	17.1	89	15.9	86	14.6	84	14.0	82	13.3	80	12.7	78	12.1	76	11.4	74	10.8	72	10.3	70	9.8	69	9.7	67	9.2	65	8.7
172	98	24.9	95	19.3	93	18.1	91	17.0	89	15.7	86	14.5	84	13.9	82	13.2	81	12.9	78	12.0	76	11.3	74	10.8	73	10.5	71	10.0	69	9.6	67	9.1	66	8.9
174	98	24.6	95	19.0	93	18.0	91	16.9	89	15.5	87	14.8	84	13.8	83	13.5	81	12.8	78	12.0	76	11.2	75	10.9	73	10.4	71	9.9	69	9.5	67	9.0	66	8.8
176	98	24.2	96	19.9	94	18.4	91	16.7	89	15.4	87	14.7	85	14.0	83	13.4	81	12.8	79	12.1	77	11.5	75	10.8	73	10.3	71	9.8	70	9.6	68	9.2	66	8.7
178	98	23.7	96	19.5	94	18.3	91	16.5	89	15.2	87	14.6	85	14.0	83	13.3	81	12.7	79	12.0	77	11.4	75	10.8	73	10.2	72	10.0	70	9.5	68	9.1	66	8.6
180	98	23.2	96	19.3	94	18.1	91	16.4	89	15.1	87	14.5	85	13.9	83	13.2	81	12.6	79	11.9	77	11.3	75	10.7	73	10.2	72	9.9	70	9.4	68	9.0	67	8.7
182	98	22.7	96	19.0	94	18.0	91	16.3	89	15.0	87	14.4	85	13.8	83	13.1	81	12.5	79	11.8	77	11.1	75	10.6	74	10.3	72	9.8	70	9.4	68	8.9	67	8.7
184	98	22.1	96	18.9	94	18.0	92	16.6	89	14.9	87	14.4	85	13.7	83	13.0	82	12.8	79	11.8	77	11.0	76	10.8	74	10.2	72	9.7	70	9.3	69	9.0	67	8.6
186	98	21.6	96	18.8	94	17.9	92	16.5	90	15.3	87	14.3	85	13.6	83	12.9	82	12.7	80	12.C	78	11.3	76	10.7	74	10.1	72	9.6	71	9.4	69	8.9	67	8.5
188	98	21.0	96	18.6	94	17.7	92	16.4	90	15.1	87	14.2	85	13.5	84	13.2	82	12.5	80	11.9	78	11.2	76	10.5	74	10.0	73	9.8	71	9.3	69	8.9	68	8.7
190	98	20.5	96	18.5	94	17.5	92	16.2	90	15.0	88	14.4	85	13.4	84	13.0	82	12.4	80	11.8	78	11.1	76	10.5	75	10.2	73	9.7	71	9.3	69	8.8	68	8.6
195	98	20.0	96	18.3	94	17.2	92	15.9	90	14.8	88	14.2	86	13.5	84	12.8	82	12.2	80	11.4	78	10.8	77	10.5	75	10.0	73	9.5	72	9.3	70	8.8	68	8.4
200	98	19.5	96	18.0	94	16.9	92	15.5	90	14.6	88	14.0	86	13.3	84	12.6	82	12.0	80	11.1	79	10.8	77	10.3	75	9.8	74	9.5	72	9.0	70	8.6	69	8.4
205	98	18.9	96	17.6	94	16.4	92	15.0	90	14.4	88	13.8	86	13.0	84	12.4	83	12.0	81	11.3	79	10.6	77	10.0	76	9.8	74	9.3	72	8.8	71	8.5	69	8.2
210	98	18.5	96	17.2	94	16.0	93	15.5	90	14.3	88	13.5	87	13.1	85	12.5	83	11.7	81	10.9	80	10.6	78	10.0	76	9.5	75	9.3	73	8.8	71	8.4	70	8.1

R.H.— Relative Humidity in per cent

E.M.C.— Equilibrium Moisture Content in per cent of the Oven-dry Weight of the Wood

RELATIVE HUMIDITY AND APPROXIMATE EQUILIBRIUM MOISTURE CONTENT OF WOOD

DIFFERENCE BETWEEN READINGS OF WET AND DRY BULBS IN DEGREES FAHRENHEIT

18		19		20		22		24		26		28		30		32		34		36		38		40		45		50		55		60		70		Dry Bulb
RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	RH	EMC	°F
																																				30
																																				35
																																				40
																																				45
																																				50
5	2.4																																			55
13	3.8	9	3.1	5	2.3																															60
20	4.8	16	4.2	12	3.5	5	2.3																													65
25	5.4	22	4.9	19	4.5	12	3.3	6	2.3																											70
30	6.0	27	5.6	24	5.1	18	4.2	12	3.3	7	2.4	1	—																							75
35	6.7	32	6.2	29	5.7	23	4.8	18	4.0	12	3.1	7	2.2	3	—																					80
38	7.1	35	6.5	32	6.0	27	5.3	22	4.5	17	3.8	13	3.1	8	2.4	4	—																			85
41	7.4	39	7.1	36	6.5	31	5.7	26	4.9	22	4.4	17	3.6	13	3.0	9	2.3	5	—	1	—															90
43	7.5	42	7.4	38	6.7	34	6.0	30	5.4	25	4.6	21	4.1	17	3.5	13	2.9	9	2.3	6	—	2	—													95
46	7.9	44	7.5	41	7.0	37	6.3	33	5.7	28	4.9	24	4.4	21	4.0	17	3.4	13	2.7	10	2.4	7	2.0	4	—											100
47	7.9	45	7.6	43	7.3	38	6.4	34	5.8	30	5.2	26	4.6	22	4.1	18	3.5	15	3.1	12	2.7	8	2.2	5	—											102
48	8.0	46	7.7	43	7.2	39	6.5	35	5.8	31	5.3	27	4.7	23	4.1	19	3.6	16	3.2	13	2.8	10	2.4	6	—											104
48	7.9	46	7.6	44	7.4	40	6.6	36	5.9	32	5.4	28	4.8	24	4.2	21	3.8	18	3.4	14	2.8	12	2.6	7	2.0											106
49	8.1	47	7.7	45	7.4	41	6.7	37	6.0	33	5.4	29	4.8	26	4.4	22	3.9	19	3.5	15	2.9	13	2.7	9	2.2											108
50	8.2	48	7.8	46	7.5	41	6.6	37	5.9	34	5.5	30	4.9	27	4.5	23	4.0	20	3.6	17	3.2	14	2.8	11	2.4											110
51	8.3	49	7.9	47	7.6	42	6.8	38	6.2	35	5.6	31	5.0	28	4.6	24	4.1	21	3.7	18	3.3	15	2.9	12	2.5											112
51	8.2	49	7.8	47	7.5	43	6.9	39	6.2	35	5.5	32	5.1	28	4.5	25	4.2	22	3.8	19	3.4	16	3.0	13	2.6											114
52	8.3	50	8.0	48	7.7	44	7.0	40	6.3	36	5.6	33	5.2	29	4.6	26	4.3	24	4.0	20	3.4	17	3.1	14	2.7											116
53	8.4	51	8.1	49	7.8	44	6.9	41	6.4	37	5.7	34	5.3	30	4.7	27	4.4	24	3.9	21	3.7	19	3.3	15	2.8											118
53	8.3	51	8.0	49	7.7	45	7.0	41	6.3	38	5.8	34	5.3	31	4.8	28	4.4	25	4.0	22	3.7	19	3.3	16	2.8	10	2.2									120
54	8.4	52	8.1	50	7.8	46	7.1	42	6.4	38	5.7	35	5.3	32	4.9	29	4.5	26	4.1	23	3.7	20	3.4	17	2.9	12	2.4									122
54	8.4	52	8.0	51	7.9	46	7.0	43	6.5	39	5.9	36	5.4	33	4.9	29	4.4	27	4.2	24	3.8	21	3.3	18	3.0	13	2.5									124
55	8.5	53	8.1	51	7.8	47	7.1	43	6.4	40	5.9	37	5.5	33	4.8	30	4.5	28	4.3	25	3.9	22	3.5	19	3.1	14	2.6									126
55	8.4	53	8.0	52	7.9	47	7.0	44	6.5	40	5.8	37	5.4	34	5.0	31	4.6	28	4.2	25	3.8	23	3.6	20	3.2	15	2.7									128
56	8.5	54	8.2	52	7.8	48	7.2	44	6.4	41	5.9	38	5.5	35	5.1	32	4.7	29	4.3	26	3.9	24	3.7	21	3.3	15	2.6	10	2.1							130
56	8.4	54	8.1	53	7.9	49	7.3	45	6.5	42	6.0	39	5.6	35	5.0	32	4.6	30	4.4	27	4.0	24	3.7	22	3.4	16	2.7	11	2.2							132
57	8.5	55	8.2	53	7.8	49	7.2	46	6.6	42	5.9	39	5.5	36	5.1	33	4.7	31	4.4	28	4.1	25	3.7	23	3.5	17	2.8	12	2.3							134
57	8.4	55	8.1	53	7.7	50	7.3	46	6.6	43	6.0	40	5.6	37	5.2	34	4.8	31	4.3	28	4.0	26	3.8	24	3.6	18	2.8	13	2.3							136
58	8.6	56	8.2	54	7.9	50	7.2	47	6.7	43	5.9	40	5.5	37	5.1	35	4.8	32	4.5	29	4.2	27	3.9	24	3.5	19	2.9	14	2.4							138
58	8.5	56	8.2	54	7.8	51	7.3	47	6.6	44	6.1	41	5.6	38	5.2	35	4.8	33	4.6	30	4.2	27	3.8	25	3.6	19	2.9	14	2.4	10	2.0					140
58	8.4	57	8.3	55	7.9	51	7.2	48	6.7	44	6.0	42	5.7	39	5.3	36	4.8	33	4.5	30	4.2	28	3.9	26	3.7	20	2.9	15	2.5	11	2.1					142
59	8.6	57	8.2	55	7.8	52	7.4	48	6.7	45	6.1	42	5.7	39	5.2	36	4.8	34	4.6	31	4.2	29	4.0	26	3.7	21	3.1	16	2.6	11	2.1					144
59	8.5	57	8.1	56	7.9	52	7.3	49	6.7	45	6.0	43	5.8	40	5.3	37	4.9	35	4.7	32	4.3	29	3.9	27	3.7	21	3.0	17	2.6	12	2.2					146
60	8.6	58	8.2	56	7.8	53	7.4	49	6.7	46	6.1	43	5.7	40	5.3	38	4.9	35	4.6	32	4.3	30	4.0	28	3.8	22	3.1	17	2.6	13	2.2					148
60	8.5	58	8.2	57	7.9	53	7.3	49	6.6	46	6.0	43	5.6	41	5.4	38	4.9	36	4.7	33	4.4	30	3.9	28	3.8	23	3.2	18	2.7	13	2.2					150
60	8.4	59	8.3	57	7.8	53	7.2	50	6.7	47	6.2	44	5.7	41	5.3	39	5.0	36	4.6	33	4.3	31	4.1	29	3.8	23	3.1	19	2.7	14	2.3	10	1.9			152
61	8.6	59	8.2	57	7.7	54	7.3	50	6.7	47	6.1	44	5.7	42	5.4	39	4.9	37	4.7	34	4.4	32	4.2	29	3.8	24	3.3	19	2.7	15	2.4	11	1.9			154
61	8.5	59	8.1	58	7.9	54	7.2	51	6.7	48	6.2	45	5.7	42	5.3	40	5.0	37	4.6	34	4.3	32	4.1	30	3.8	24	3.2	20	2.8	15	2.3	11	1.9			156
61	8.4	60	8.3	58	7.8	55	7.4	51	6.7	48	6.1	45	5.7	43	5.4	40	4.9	38	4.7	35	4.4	33	4.2	30	3.8	25	3.3	20	2.8	16	2.4	12	2.0			158
62	8.5	60	8.2	58	7.8	55	7.3	52	6.8	49	6.3	46	5.8	43	5.3	41	5.0	38	4.7	35	4.4	33	4.1	31	3.9	25	3.2	21	2.8	17	2.5	13	2.1			160
62	8.4	60	8.1	59	7.9	55	7.2	52	6.7	49	6.2	46	5.7	44	5.4	41	5.0	39	4.8	36	4.4	34	4.2	31	3.9	26	3.3	22	2.9	17	2.4	13	2.1			162
62	8.4	61	8.2	59	7.8	56	7.3	52	6.6	49	6.1	47	5.8	44	5.3	41	4.9	39	4.7	36	4.4	34	4.2	32	3.9	26	3.3	22	2.9	18	2.5	14	2.2			164
63	8.5	61	8.1	59	7.8	56	7.3	53	6.7	50	6.2	47	5.7	44	5.3	42	5.0	39	4.7	37	4.4	35	4.2	32	3.9	27	3.4	23	2.9	18	2.5	14	2.2			166
63	8.4	61	8.0	60	7.9	56	7.2	53	6.6	50	6.1	47	5.6	45	5.4	42	4.9	40	4.7	37	4.4	35	4.2	33	3.9	28	3.4	23	2.9	19	2.6	15	2.3			168
63	8.3	62	8.2	60	7.8	57	7.3	53	6.5	51	6.2	48	5.7	45	5.3	43	5.0	40	4.7	38	4.4	35	4.2	33	3.9	28	3.4	24	2.9	19	2.5	15	2.2			170
64	8.4	62	8.1	60	7.7	57	7.2	54	6.7	51	6.1	48	5.7	46	5.4	43	5.0	41	4.8	38	4.4	36	4.2	34	4.0	28	3.4	24	2.9	20	2.6	16	2.3			172
64	8.4	62	8.0	61	7.8	57	7.1	54	6.6	51	6.0	49	5.7	46	5.3	43	4.9	41	4.7	39	4.5	36	4.2	34	3.9	29	3.4	24	2.9	20	2.6	16	2.2			174
64	8.3	63	8.1	61	7.7	58	7.2	55	6.7	52	6.1	49	5.7	46	5.3	44	5.0	42	4.8	39	4.4	37	4.2	35	4.1	29	3.4	25	3.0	21	2.7	17	2.3			176
64	8.2	63	8.0	61	7.7	58	7.1	55	6.6	52	6.1	49	5.7	47	5.4	44	4.9	42	4.7	39	4.4	37	4.2	35	4.0	30	3.4	25	2.9	21	2.6	17	2.3			178
65	8.4	63	7.9	62	7.8	58	7.1	55	6.5	52	6.0	50	5.7	47	5.3	45	5.0	42	4.7	40	4.5	38	4.3	35	3.9	30	3.4	26	3.0	22	2.7	18	2.4			180
65	8.3	63	7.8	62	7.7	59	7.2	56	6.7	53	6.1	50	5.7	48	5.4	45	5.0	43	4.8	40	4.4	38	4.2	36	4.0	31	3.5	26	3.0	22	2.7	18	2.4			182
65	8.2	64	7.9	62	7.6	59	7.1	56	6.6	53	6.0	50	5.6	48	5.3	45	4.9	43	4.7	41	4.5	38	4.2	36	4.0	31	3.4	27	3.1	22	2.6	19	2.4			184
65	8.3	64	7.9	62	7.5	59	7.0	56	6.5	53	5.9	51	5.7	48	5.3	46	5.0	43	4.7	41	4.4	39	4.3	37	4.1	32	3.6	27	3.1	23	2.7	19	2.4			186
66	8.2	64	7.8	63	7.6	59	6.9	57	6.6	54	6.0	51	5.6	49	5.4	46	4.9	44	4.8	41	4.4	39	4.2	37	4.0	32	3.5	27	3.0	23	2.6	20	2.4			188
66	8.1	65	7.9	63	7.5	60	7.0	57	6.5	54	6.0	51	5.6	49	5.3	46	4.9	44	4.7	42	4.5	39	4.2	37	3.9	32	3.4	28	3.1	24	2.7	20	2.4			190
67	8.1	65	7.7	64	7.6	61	7.0	58	6.5	55	6.0	52	5.6	50	5.3	47	4.9	45	4.7	43	4.5	40	4.2	38	4.0	33	3.6	29	3.1	25	2.8	21	2.4	15	2.0	195
67	7.9	66	7.8	64	7.4	61	6.9	58	6.3	55	5.9	53	5.5	51	5.3	48	4.9	46	4.7	43	4.4	41	4.2	39	4.0	34	3.5	30	3.2	26	2.8	22	2.5	16	2.1	200
68	7.9	66	7.6	65	7.4	62	6.8	59	6.3	56	5.9	54	5.6	51	5.2	49	4.9	46	4.7	44	4.4	42	4.3	40	4.0	35	3.5	31	3.2	27	2.8	23	2.6	17	2.1	205
68	7.8	67	7.5	65	7.2	62	6.7	60	6.3	57	5.9	54	5.4	52	5.1	49	4.8	47	4.7	45	4.4	43	4.3	41	4.0	36	3.6	32	3.2	28	2.8	24	2.6	18	2.2	210

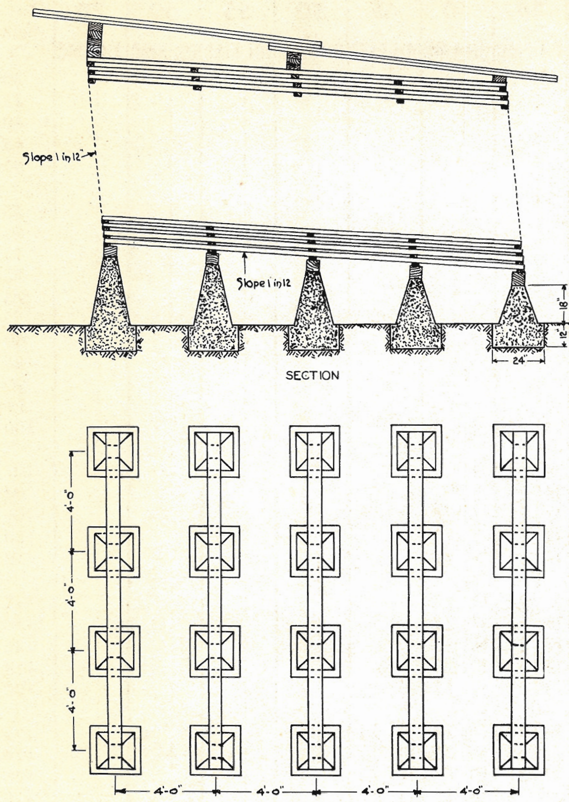


FIGURE 17.—Suggested Foundation and Piling Arrangement for Air-seasoning.

4. Supports should be of sufficient size to prevent bending and sagging of the lumber between piers. When rectangular pieces (e.g. as 6 by 8 inches) are used, they should be placed on edge to utilize the full stiffness of the support.

5. When possible, similar lengths should be segregated and placed in separate piles. If this is not possible, they should be box-piled. This eliminates overhanging ends and reduces the amount of warping and splitting. All crossers should be aligned over the cross supports. In addition to the horizontal slope of the pile, the front face of the pile should slope outwards approximately 1 in 12 to allow rain to drip off and not run into the pile. The front tiers of crossers should extend approximately ½ inch beyond the ends of the lumber to act as a sunshade.

6. The usual practice in piling lumber for air-seasoning is to use the material being piled as crossers. The use of prepared crossers assists in keeping lumber straight. These should be dressed uniformly from one-inch material, two to four inches in width. Wider crossers may be used at the front and rear of each course. When piling hardwood less than 2 inches in thickness, crossers should not be placed more than 2 feet apart. When piling hardwood 2 inches or over in thickness and all thicknesses of softwoods, crossers may be placed up to 4 feet apart.

7. Piling should be done in such a manner as to provide sufficient circulation to prevent stain and decay in species which are susceptible to this form of de-grade. Since the general flow of air circulation in a pile which is being air-seasoned enters at the top and proceeds from the top to the bottom and out at the bottom of the pile, care must be taken that vertical flues are provided which do not block off the circulating air at any point. Spacing between the sides of the piles should be from two to four feet.

8. Protection from the elements should be provided when the pile is completed, to prevent excessive exposure to the sun and rain. Roofs may be made by placing two layers of a low grade of lumber longitudinally, with the boards of the top tier overlapping the joints in the lower tier and so placed that there is adequate circulation between the top of the pile and the roof. Prepared sections of roof may be put in position easily and quickly. Sections of corrugated metal roofing are also very useful for this purpose. Protection should also be provided for partially completed piles if there is a possibility that further piling will be suspended for some time.

9. When lumber is piled by hand, there is very little danger of the piles being high enough to cause a superimposed load on the crossers sufficient to cause crushing of the wood. However, care should be taken to provide additional crossers to increase the bearing area if there is a possibility that the lumber will be piled high enough to cause crushing.

10. The practice of placing unit bundles of lumber in a pile by means of lift trucks is becoming common. The unit bundles of lumber are placed 3 or 4 units high, with 2 by 4 inch spacers on edge between each unit. Care must be taken that sufficient spacers are placed in vertical alignment to prevent warping of the lumber. At least five per 16 feet of lumber should be used.

Plates 51 and 52 show models of piles constructed to illustrate good and poor piling practice.

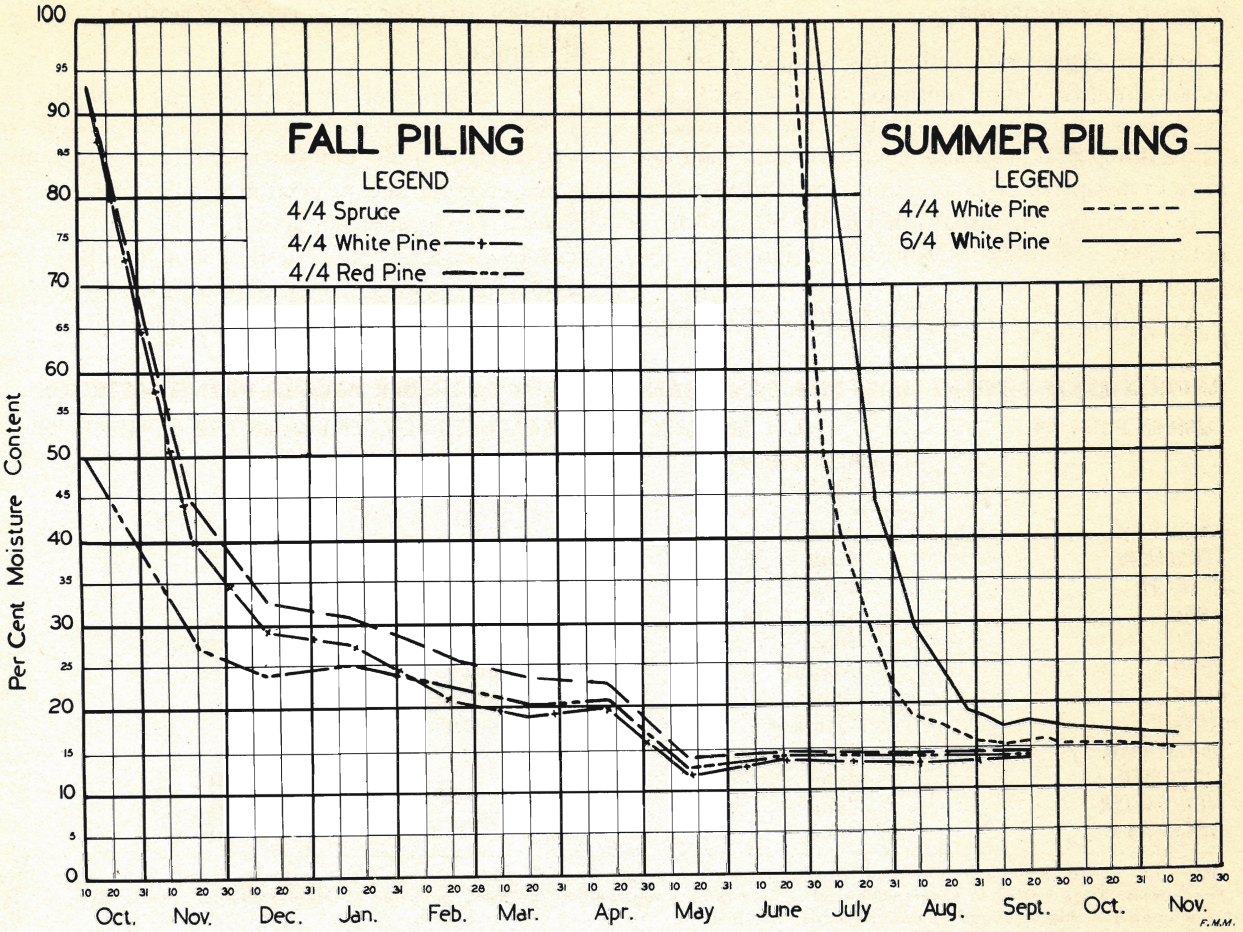
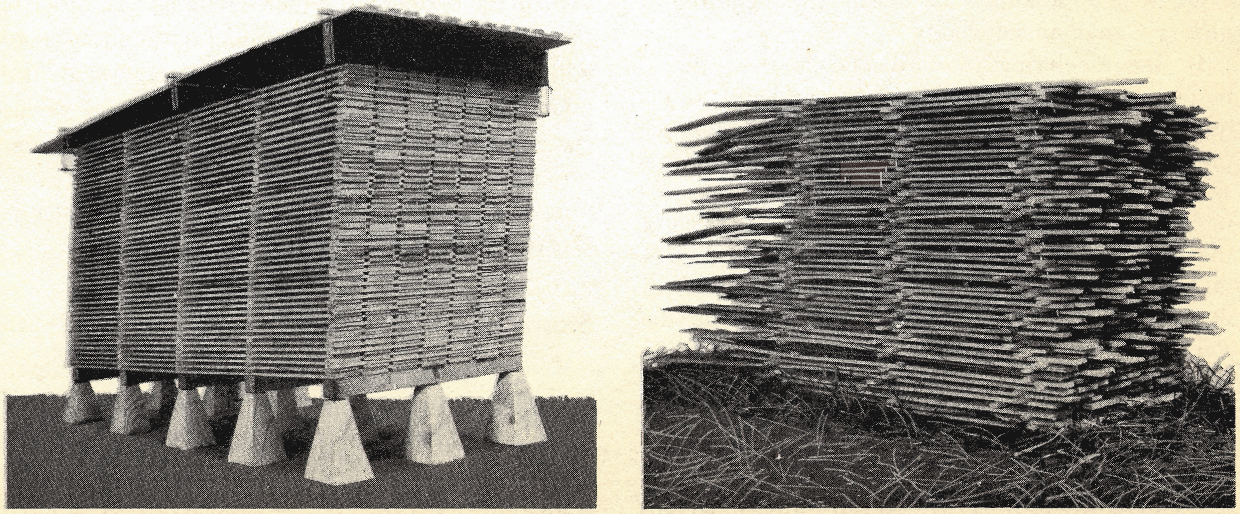


FIGURE 18.—Drying Rates of Lumber Air-seasoned at Ottawa.



Plates 51 & 52.—Models Showing Good and Bad Piling Practice.

Rates of Air-seasoning

Several factors affect the time required to air-season lumber. The softwood species, with few exceptions, dry more quickly than the hardwoods. Thick lumber takes much longer than thin. Lumber piled in the spring dries sometimes in about six weeks to two months, while that piled in the autumn may not reach a similar moisture condition until the next summer.

As explained in the section dealing with equilibrium moisture content, air-dry condition in Canada may mean 12 per cent to 20 per cent moisture. Table 17 gives an approximate idea of the time required to air-dry Canadian softwoods.

In the air-drying of hardwood lumber, birch, maple, beech, and elm may be considered as requiring about the same time to dry. For lumber under 3 inches in thickness, this time is usually from six months to eighteen months, its duration depending on the thickness of the lumber and the time of the year when the piling was done. Hardwood 4 inches in thickness may take two or more years to dry. Ash dries more quickly, approximating the softwood rate, and basswood dries even more quickly than some softwoods. Oak, on the other hand—especially white oak—usually takes much longer than most hardwoods.

Figures 18 and 19 illustrate the drying rate of representative boards in actual piles in Eastern Canada and British Columbia.

TABLE 17

APPROXIMATE DRYING TIMES FOR CANADIAN SOFTWOODS UNDER PROPER PILING METHODS

LUMBER PILED IN	MAY BE EXPECTED TO REACH 20 PER CENT MOISTURE CONTENT IN		
	1-inch, 1 1/4-inch, 1 1/2-inch	2-inch	3-inch
JANUARY	June	July	August
FEBRUARY	June	July	August
MARCH	July	July	August
APRIL	July	July	August
MAY	July	July	September
JUNE	August	September	October
JULY	September	October	May
AUGUST	October	May	June
SEPTEMBER	May	June	July
OCTOBER	June	July	August
NOVEMBER	June	July	August
DECEMBER	June	July	August

Note—The above should be considered as a conservative average. Special conditions may result in faster drying, but, on the other hand, some of the lumber in lower sections of piles may even lag behind the times indicated unless exceptional care is taken to provide adequate drainage and ventilation under the piles.

Amount of De-grade or Depreciation of Lumber

The amount of de-grade in air-seasoning is generally inversely proportional to the amount of care taken in laying out and maintaining yards, and in the erection and protection of piles. In cases of extreme carelessness, an actual loss of nearly 50 per cent of the total value of the stock has been experienced. In general, estimates run between 7 per cent and 10 percent in well-kept yards.

Species which are affected by stain, such as white pine and certain of the hardwoods, show the greatest percentage of de-grade in air seasoning. In order to prevent staining, fairly open piling is usually adopted with a view to quick drying. However, with this open piling the danger of severe checking is increased, and it may be necessary to effect a compromise. More detailed information on the prevention of decay and stain is contained in Chapter 6, Decay and Stains in Wood.

Storage of Air-seasoned Lumber

When the output of a mill finds a ready market, manufacturers usually do not need to consider storage to any great extent, as the lumber is shipped direct from the drying pile. During periods of dull trade, however, storage may become a problem.

Since there is little danger of stain or decay in

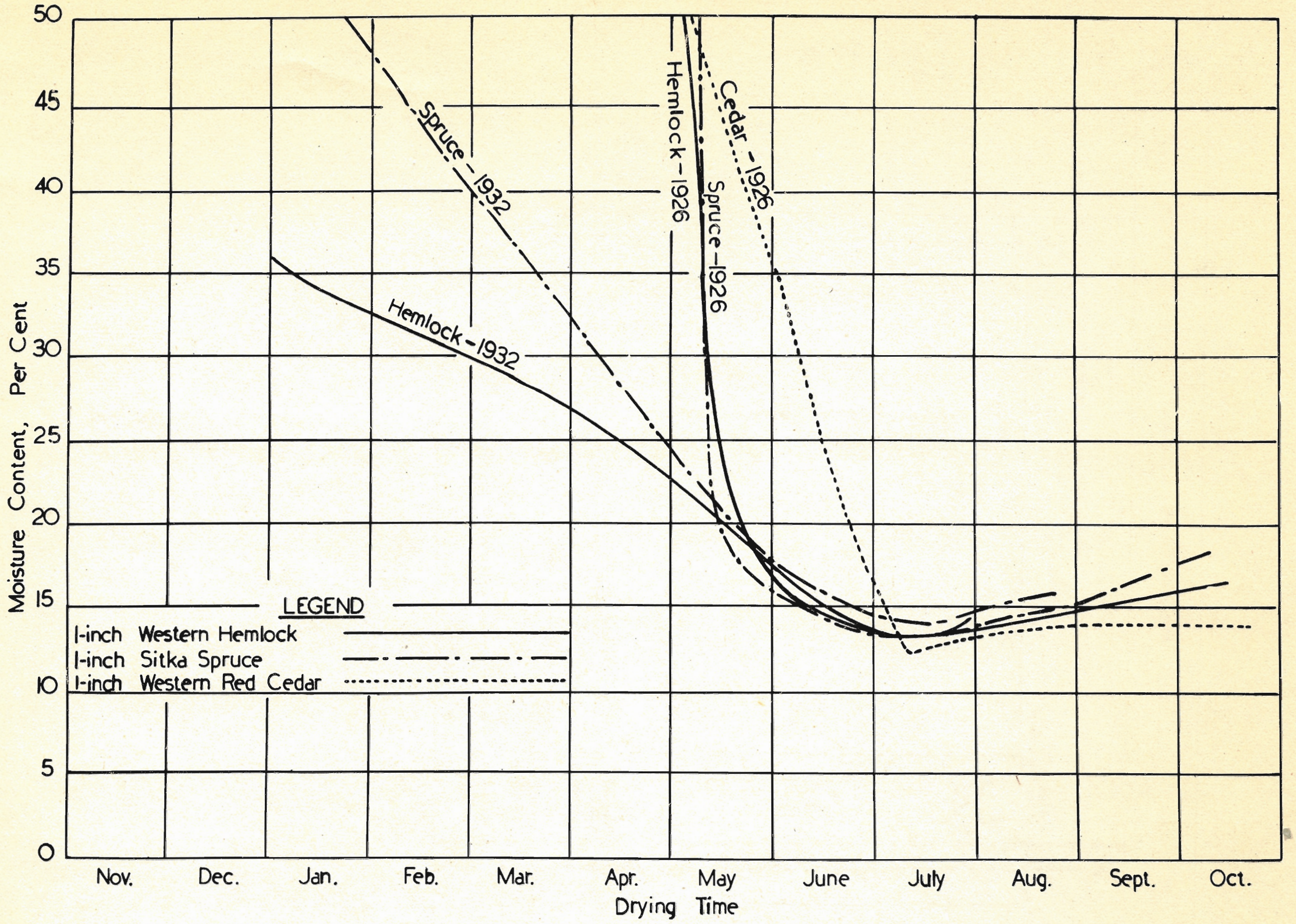


FIGURE 19.—Drying Rates of Lumber Air-seasoned in the Southern Coast Region of British Columbia.

lumber dried to a moisture content of less than 20 per cent, thoroughly air-dried lumber may be close-piled without crossers in the summer season. In close piles it will pick up less moisture during the winter months than in open piles. It will also retain its brightness and will not become weathered or water-stained, provided it is properly roofed. Close-piling also has the advantage of tending to straighten stock which has twisted in open piling. Good ventilation under close piles is essential; tight, amply projecting roofs are also necessary.

If air-dried lumber is stored in a heated shed or kept for fairly long periods in a heated factory it will lose moisture. The amount of the loss will depend on the temperature and humidity conditions of the place in which it is stored and on whether or not it is stickered. For practical purposes, lumber which has reached a low moisture content in this way may be classed as kiln-dried stock, provided it has reached a moisture content which is low enough for the purpose intended.

DRY-KILN SEASONING

Types of Dry-kilns

Dry-kilns are classed on the basis of their operation as "compartment" or "progressive" types. The compartment type is sometimes called a "chamber" or "charge" kiln. On the basis of the air circulation they are classed as "natural" or "forced" circulation kilns.

(a) COMPARTMENT TYPE

In the compartment type, the kiln is completely charged with lumber at one operation. This lumber remains stationary in the kiln until drying is completed, when the entire charge is removed. Temperature and humidity conditions in the kiln are varied, as the drying progresses, by means of valves controlling the heating and humidifying systems. Drying conditions in this type of kiln are independent of its length, can be controlled easily, and can be varied to suit the lumber being dried; such a kiln may use either natural or forced circulation.

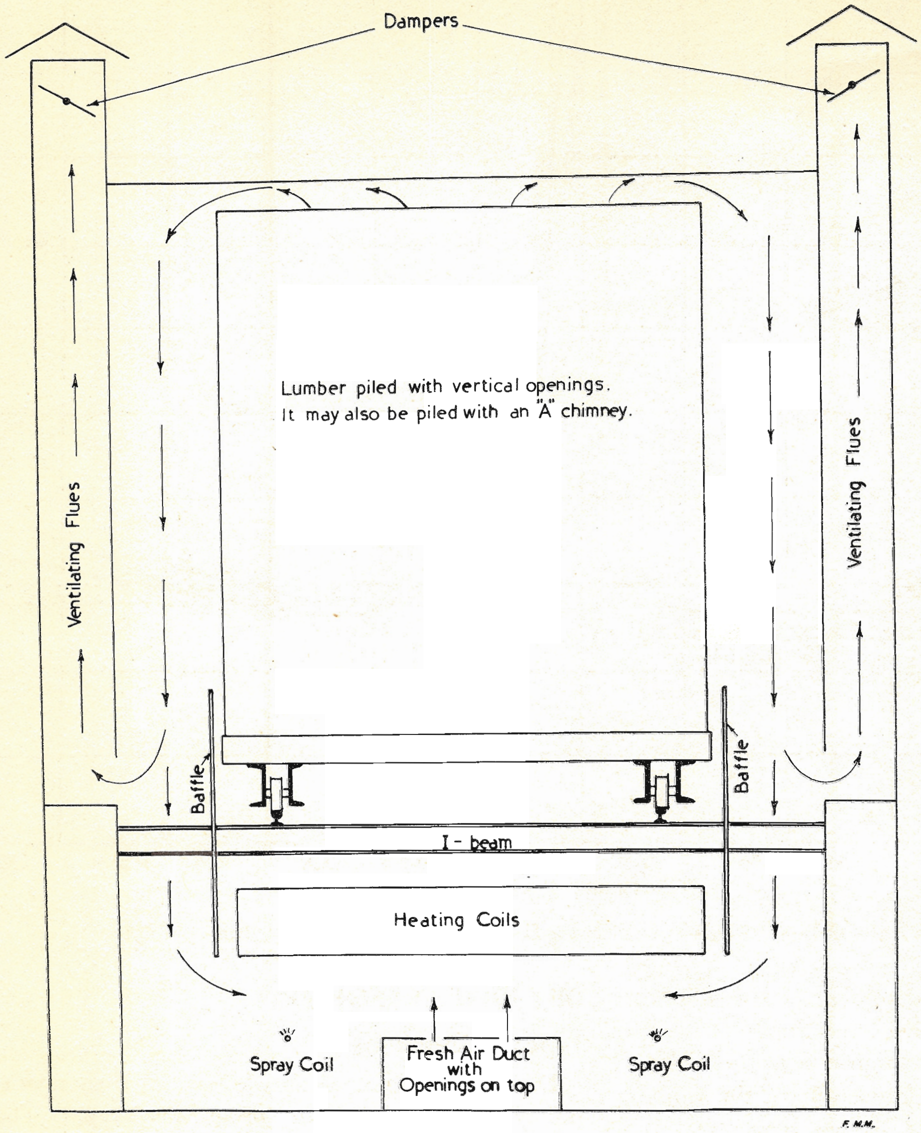


FIGURE 20.—Natural Circulation Kiln.

Natural Circulation Kiln

In natural circulation kilns, air circulation is obtained by natural means, i.e., the tendency of hot air to rise and cool air to descend. Such kilns are generally constructed along the lines shown in Figure 20. In this arrangement, fresh air is brought into a duct which is below the heating units and extends longitudinally along the centre of the kiln. The air duct is fitted with adjustable dampers by which the amount of fresh air which enters the kiln may be regulated.

This duct has openings on the top from which the fresh air emerges to be heated and humidified by the heating coils and spray pipes. From here it continues upward through the vertical flues in the lumber pile. Then it moves horizontally between the tiers of lumber to the sides of the pile. By this time the air has cooled considerably and absorbed moisture from the lumber. This causes it to descend between the side of the pile and the side wall of the kiln. As it descends, it passes ventilator openings which carry off a portion of the moist air and exhaust it through the ventilating flues. These flues are fitted with dampers which assist in controlling the humidity conditions in the kiln and in regulating the amount of moist air which is exhausted.

Continuing its descent, the moist air passes below the rail level between the wall and baffle which separates the rising hot air from the descending cooler air. Then it passes under the baffle and is recirculated through the heating coils.

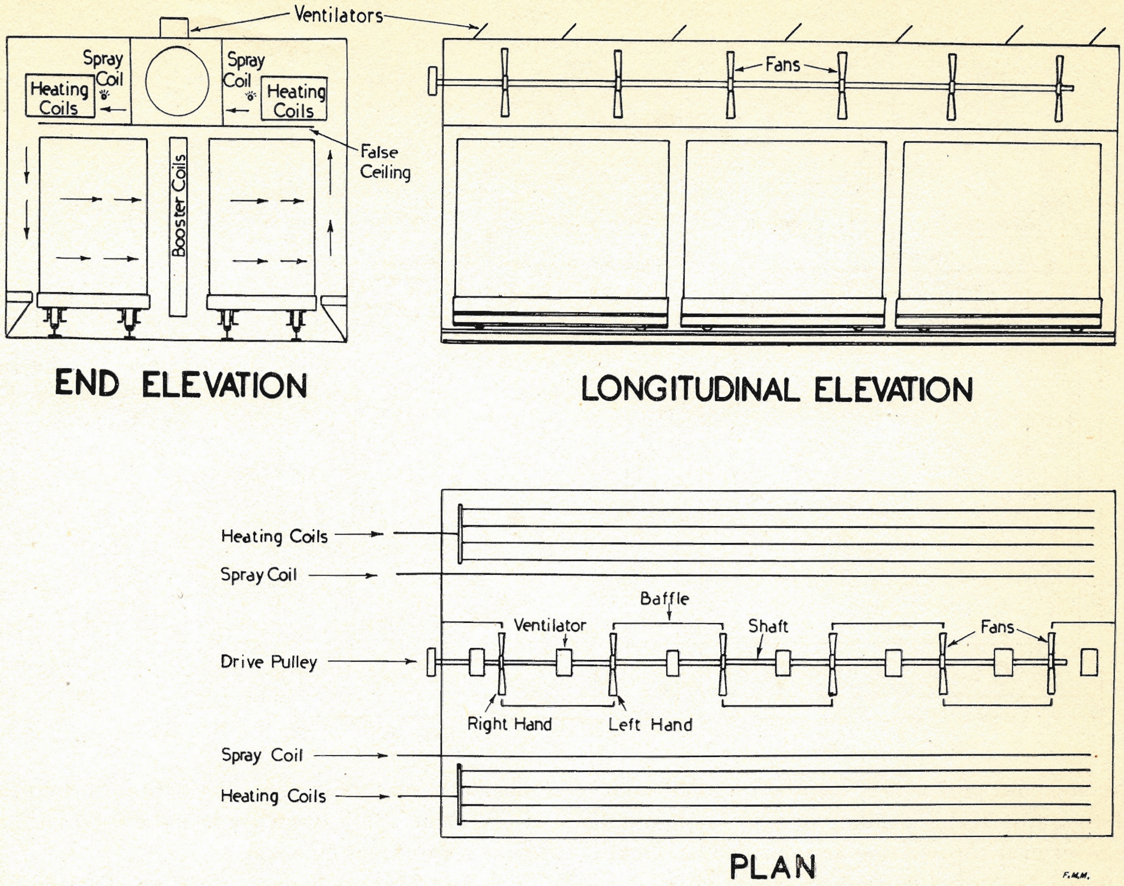


FIGURE 21.—Internal-fan, Cross-circulation, Longitudinal-shaft, Compartment Kiln.

Forced Circulation

In the forced circulation type, the circulation is obtained by mechanical means. The type may be subdivided into two classes: (1) the internal fan, (2) the external blower.

Internal Fan Kiln

The internal fan class of kiln may be built in several styles, but three of the commonest only will be described here.

Figure 21 is a schematic drawing of an internal-fan, cross-circulation, longitudinal-shaft, compartment kiln. In this type, a number of fans are mounted on one longitudinal shaft. To provide more uniform circulation, and to prevent end-drift, the fans are generally mounted alternately left- and right-handed for use with baffles as shown. The direction of circulation is changed periodically by reversing the direction of rotation of the fans.

The air is drawn in through alternate ventilators, passes through the fans, and is deflected crosswise of the kiln by the baffles. Then it passes across the heating and spray coils, where it is conditioned according to the drying schedule selected for the specific species, dimension, and moisture content of the lumber which is being dried. After being conditioned, it passes down the side of the kiln between the lumber and the side wall. As it passes downward, the pressure developed in this narrow space forces it to flow crosswise of the lumber pile between the tiers of boards, which have been piled lengthwise of the kiln.

Figure 21 illustrates a double-track kiln in which a booster coil is used to raise the temperature after it has dropped in passing through the first pile. After the hot air passes through the second pile, it ascends between the pile and the wall of the kiln, and continues through the second set of heating and spray coils to be partially reconditioned. A portion of the moist air is exhausted through the ventilators, and the remainder continues through the fans and is recirculated and conditioned as before.

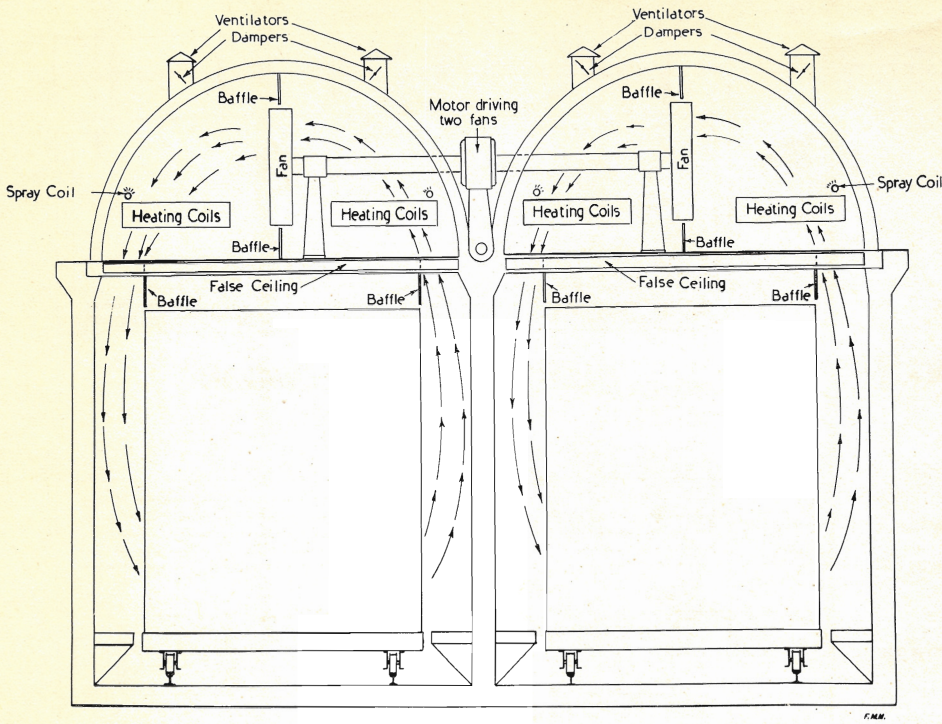


FIGURE 22.—Internal-fan, Cross-circulation, Cross-shaft Kiln.

The fans and piping may also be installed underneath the rails. If this is done, the ventilators usually are placed in two rows, one at each side of the kiln. This form of ventilation may also be used when the fans and piping are installed in the ceiling of the kiln.

Figure 22 is a schematic drawing of an internal-fan, cross-circulation, cross-shaft dry-kiln. The principle of operation of this type of kiln is similar to that illustrated in Figure 21. The chief difference is in the method of installing the fans, each fan is mounted on an individual shaft placed crosswise of the kiln, and one baffle extends down the centre of the kiln. Openings in which individual fans are placed are cut in this baffle at intervals. Thus, the circulation is directly across the kiln without the necessity of deflecting it from a longitudinal to a transverse direction.

In the diagram shown, two fans of adjacent kilns are run by the same motor. The fans may also be operated by using one longitudinal shaft which extends along the outside of the kiln. Pulleys at suitable intervals on this shaft may be connected to others on the individual crosswise shafts by quarter-turn belts.

The practice of installing individual fan and motor units inside the kiln is a variation of this assembly. In this arrangement it is necessary to use specially insulated motors to resist the action of the moisture in the kiln. Both types are usually fitted with means to reverse the circulation.

Figure 23 is a schematic drawing of a modification of the internal fan, cross-circulation, cross-shaft dry-kiln. The principle of operation of this type is the same as that shown in Figure 22, except that only one heating and spray unit is used. Booster coils are provided if more than one row of tracks is used. The chief difference between this type and that shown in Figure 22 is in the arrangement of the fans: in this kiln, the individual fans are mounted in a false wall at one side of the kiln.

Individual motors to drive each fan shaft may be used, or two adjacent fan shafts may be connected to one motor. One longitudinal shaft with pulleys at suitable intervals may also be connected to others on the individual shafts by quarter-turn belts. This type may be fitted with means to reverse the circulation.

There is also found another type of external-blower dry-kiln. In this type, fresh air is drawn in through a damper in the duct which leads to the blower. The air passes through the blower into a duct and continues through a conditioning chamber which contains spray and heating coils. From the conditioning chamber, the air is forced into a duct

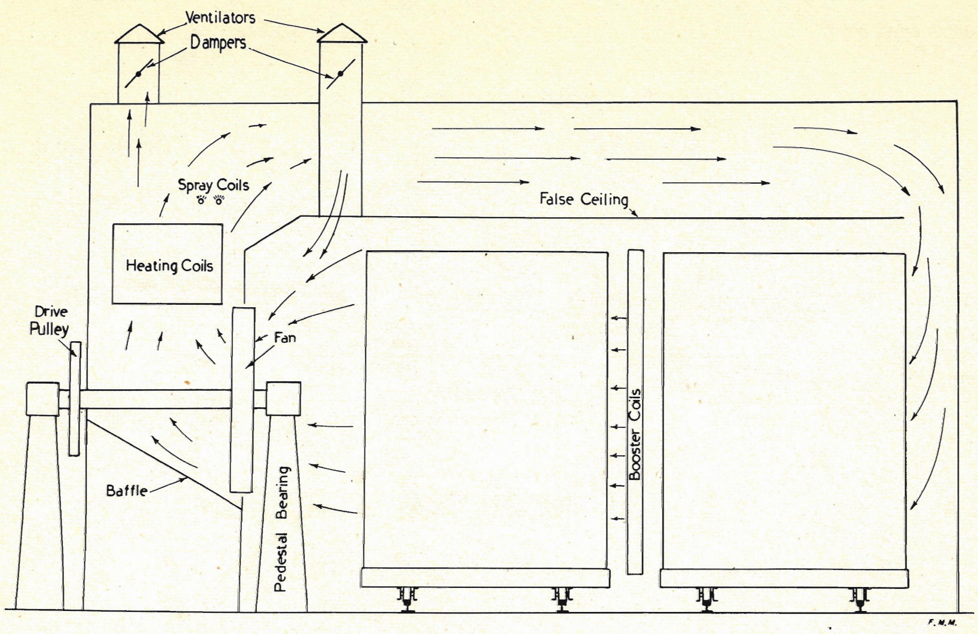


FIGURE 23.—Internal-fan, Cross-circulation, Cross-shaft Kiln.

which extends longitudinally along the floor of the kiln and under the centre of the lumber, which has been piled lengthwise of the kiln with an A-shaped chimney through the centre of the pile. Openings in the top of the duct allow the air to rise through the chimney, from which it is deflected across the lumber. When the air reaches the sides of the kiln, a portion of it, depending on the humidity conditions, may be exhausted through ventilators. The rest travels down the sides of the kiln, enters the return ducts, and is returned to the fan, recirculated, and reconditioned to repeat the cycle.

The chief difference between the plate-type and this pattern of kiln is in the method of introducing the hot air into the kiln. Instead of forcing the air up and through the lumber pile, this type forces the air into a pressure chamber, placed longitudinally between the two rows of lumber piles in the kiln. Holes in each side wall of this chamber permit the air to emerge and pass horizontally across the lumber piles and enter the return air chambers through holes in the side walls. This type may be fitted with means to reverse the circulation.

(b) PROGRESSIVE TYPE

In the progressive type of kiln, cars of lumber are loaded into one end (the wet end) of the kiln and move progressively to the opposite end (the dry end). The temperature and humidity conditions vary throughout the kiln so that eventually each car of lumber is subjected to conditions which are more or less similar to those specified in standard drying schedules.

Figure 24 is a schematic drawing of a natural-longitudinal-circulation progressive dry-kiln.

In the longitudinal-circulation type, fresh air enters at the dry end of the kiln through one or more ducts which extend at floor level approximately one-third the length of the kiln. These ducts are fitted with dampers to regulate the supply of fresh air.

In the drying process, air passes through the heating coils at the dry end and, after being heated, first rises above the tracks and then passes longitudinally through the lumber toward the wet end. As it moves along, its temperature drops and the relative humidity increases as a result of the cooling effect of the wet lumber and the moisture which it gives off. Best results are obtained when the cooling of air and increase in relative humidity produce conditions which are similar to a drying schedule used in a compartment kiln. A spray coil may be installed at the wet end to increase the humidity at this point, if it is found that the increase obtained by means of the moisture driven off the wood is not sufficient. An auxiliary spray coil may also be installed at the dry end, to be used when required to reduce case-hardening.

As the air reaches the wet end, a portion of it escapes to the outside through the ventilator stack.

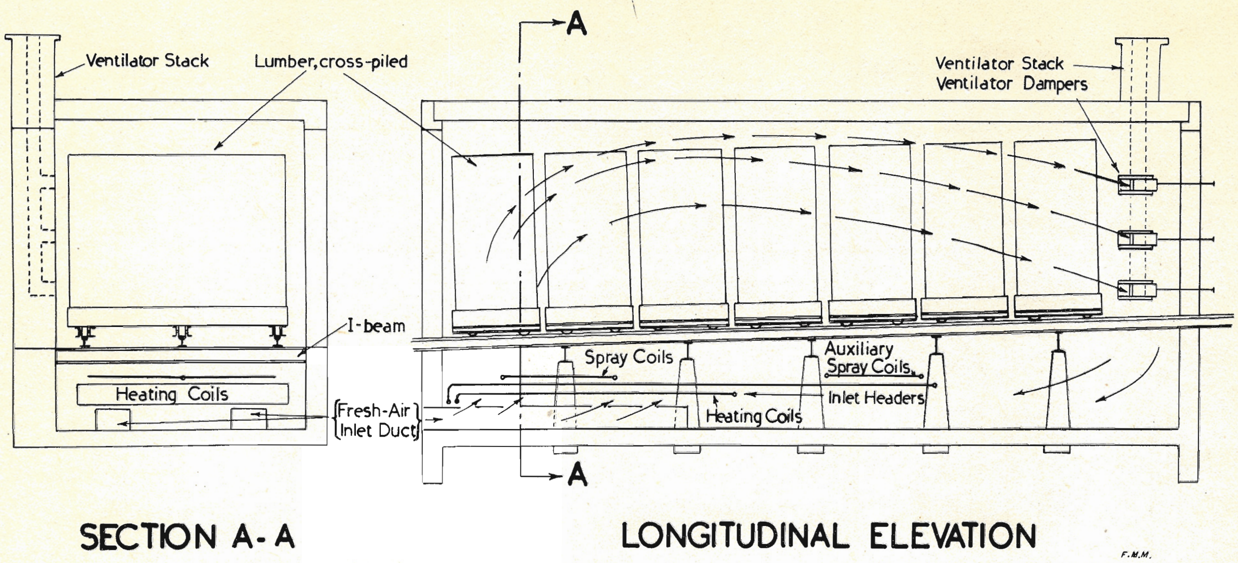


FIGURE 24.—Natural-longitudinal-circulation Progressive Kiln.

The remainder of the circulating air descends and passes longitudinally along the floor of the kiln until it is drawn upward by the hot air currents through the heating system and recirculated.

Figure 25 is a schematic drawing of a natural-cross-circulation progressive dry-kiln. This is very similar to the longitudinal-circulation type. The chief difference is that instead of the lumber being cross-piled as shown in Figure 24, it is end-piled, and the fresh air ducts, heating and spray coils, and ventilators are installed as in the natural-circulation kiln shown in Figure 20.

Advantages and Disadvantages of Each Type

Each type of dry-kiln has its advantages and disadvantages. The chief advantages and disadvantages of each type are as follows:

TYPE OF KILN	ADVANTAGES	DISADVANTAGES
COMPARTMENT	**More flexible for all sizes of charges. Definite schedules for each charge. Easy to correct case-hardening. Faster drying than in progressive kiln. Can be shut down or started easily. Good air circulation.**	**Needs close supervision. Requires extensive storage space and careful planning to ensure proper flow of dried lumber.**
PROGRESSIVE	**Relatively simple to load and operate. Supplies a continuous output of dry lumber.**	**Difficult to control and vary drying conditions in different zones. Not flexible in operation and will not operate satisfactorily under a length of 60 feet.**
NATURAL CIRCULATION	**Low first cost. Simple to erect. No moving parts to get out of order.**	**Slow circulation. Possible stain in some species which are very wet, owing to this slow circulation.**
MECHANICAL CIRCULATION	**Good circulation. Faster drying than natural circulation.**	**More expensive than natural circulation. Moving parts may get out of order.**

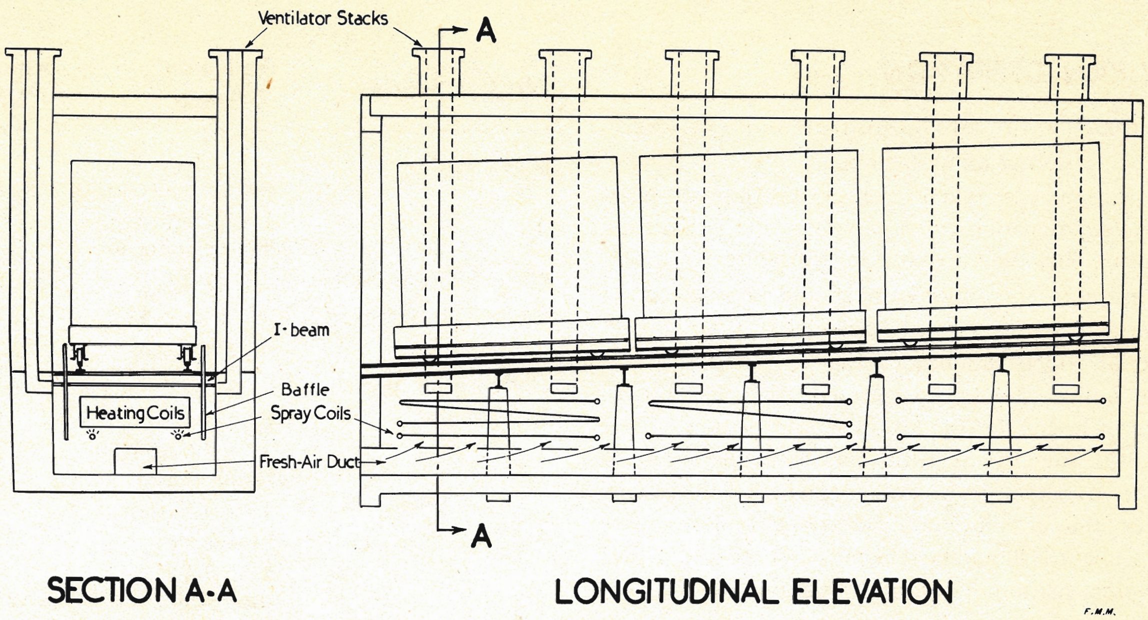


FIGURE 25.—Natural-cross-circulation Progressive Kiln.

KILN EQUIPMENT

Heating System

The heating system should have sufficient excess heating capacity over that required for general operating conditions to bring the kiln up to the required temperature quickly. Two types of heating arrangements are used most frequently, the header type and the multiple-return-bend header coil. The latter type provides uniform temperature conditions in long kilns.

All heating systems should be provided with steam traps of sufficient capacity to remove all the condensate, otherwise it may not be possible to obtain the desired temperature conditions.

Control Instruments

The valves on the heating and humidifying systems in a dry-kiln may be controlled manually or by automatic mechanical control through a thermostat. Automatic control of the kiln temperature is strongly recommended where accurate drying is required.

When the steam valves are operated manually, it is necessary to use a wet and dry bulb hygrometer to determine the temperature and relative humidity in a kiln at any time. Then the valves may be adjusted by hand until the required conditions are obtained. Maximum recording thermometers in the hygrometer permit reading of the kiln temperature after the hygrometer has been removed from the kiln. This method requires a great deal of supervision to ensure that the adjustment of the valves to produce the required conditions is correct.

Temperature recorders should be installed in all kilns which are manually operated, to record the conditions during operation and for reference purposes at a later date.

Air-operated recorder controllers are generally used in dry-kilns. These are divided into two classes, the direct-acting and the reverse-acting. In the direct-acting instruments, the steam diaphragm valve is kept open by a spring until the desired temperature is reached. At this point, air pressure is admitted to the diaphragm valve, forcing the diaphragm down, closing the valve, and cutting off the steam. In reverse-acting instruments, the diaphragm valves are so constructed that they are opened by the air-pressure and closed by the springs, which is the reverse of the action of the direct-acting type. The advantage of the reverse-acting type lies in the fact that a failure of the air supply causes the valves to shut, preventing a dangerous rise in temperature.

An instrument for the automatic control of the volume of air exhausted through the roof vents is used to a considerable extent at the present time. The instrument is actuated by the wet bulb of the controller and consists of a diaphragm-operated lever which opens and closes the vents.

DRY-KILN OPERATION

Satisfactory dry-kiln operation requires very careful supervision of many factors.

Care should be taken to check the controls, heating system, and all moving parts of a kiln periodically to ensure that they are working correctly.

If possible, the kiln charge should be made up of material of one species and dimension. Failing this, material which requires drying schedules that are quite similar should be selected, and the mildest drying schedule for the group should be used. Care should be taken to align the stickers properly and to prevent overhanging board edges which would short-circuit the circulation. Sufficient representative sample boards should be selected and prepared to give a good indication of drying throughout the kiln run.

Kiln-drying Schedules

Definition

A drying schedule is a set of directions for the operation of a kiln during the drying period. The schedules vary with the species, size, and grade of lumber being dried, and are usually presented in the form of tables showing the temperatures and humidities to be used at various stages of the process. The changing temperatures and humidities in the drying schedules are based either on the period of drying or on the moisture content of the lumber.

TABLE 18

DRYING SCHEDULES FOR VARIOUS SPECIES

	SCHEDULE NUMBER FOR DIFFERENT THICKNESSES, IN INCHES	
Eastern Species	1-1 ½″	1 ¾-2 ¼″
Aspen (Poplar)	12	13
Basswood	12	13
Beech	19	20
Birch	13	14
Cedar (eastern white)	6	7
Cottonwood	12	13
Elm	14	15
Fir, Balsam*	1	2
Hemlock	5	6
Maple	15	16
Oak	17	18
Pine, Jack	3	4
Pine, White	10	11
Pine, Red	3	4
Spruce	8	9

*When dried in combination with spruce, use spruce schedule.

Western Species	Dimension & Grade	Schedule No.
Alder, Red	1-1 ¼″ stock not subject to collapse	35
	1-1 ¼″ stock subject to collapse	43
Birch, Western White	1-1 ¼″	36
Cedar, Western Red	1″ x 6-8″	32
	1 ¾″-2 ¼″	33
Cottonwood, Black	1″ mill-run	41
Fir, Douglas	Clears:	
	1″ x 4″ strips (edge-grain)	22
	1″ x 4″ strips (flat-grain)	21
	1″ x 8-12″ (flat-grain)	23
	1″ x 14″ (flat-grain)	24
	2″ x 12″ (flat-grain)	25
	3″ and 4″ (flat-grain)	26
	Door stock and factory lumber:	
	1 ½″ x 4-10″ (edge-grain)	27
	1 ¾″ x 4-10″ (edge-grain)	28
	Common:	
	1″ (natural circulation)	29
	2″ (natural circulation)	30
	1″ (mechanical circulation)	31
Hemlock, Western	1-1 ¼″ box shook	36
	1-2″ clears	37
	2″ aero grade	38
Larch, Western	1″ stock up to 10″ wide	42
Maple, Broadleaf	1-1 ¼″	36
Pine, Ponderosa	1-1 ½″	1
	1 ¾-2 ¼″	6
Pine, Western White	1-2″ selects and shop	34
Spruce, Engelmann	1-2″	40
Spruce, Sitka	1″	6
	2″	39
Spruce, Western White	1-2″	40

Use of Drying Schedules

The following tables list drying schedules which may be followed in drying various species and dimensions of lumber. Since every kiln has its own drying characteristics, the schedules are recommended as guides only, subject to adjustment to suit each particular kiln.

It will be noted that while the schedules listed for eastern species are based on moisture content, those for western woods are based on elapsed drying time. Use of the latter greatly simplifies kiln operation. However, certain factors favour the use of these time-based schedules on the west coast, but hinder their application in Eastern Canada. Most of the lumber kiln-dried on the west coast is dried green from the saw, consequently its initial moisture content will consistently fall within a certain known range. In Eastern Canada however, lumber to be kiln-dried generally enters the kiln in an air-dry or partially air-dry condition, with considerable variation in moisture content. A time-based schedule applicable to one charge may be inadequate for the next. In Eastern Canada there is also a greater variation in the drying characteristics of individual kilns than on the west coast, running all the way from a modern forced-circulation kiln to an antiquated "hot-box". This is the most important factor preventing the widespread application of time-based schedules in Eastern Canada at the present time. Any kiln operator who has become sufficiently familiar with drying certain species and dimensions by using schedules based on the moisture content of the lumber can easily draw up time-based schedules applicable to his particular kiln.

DETAILED DRYING SCHEDULES

TABLE 19

SCHEDULE NUMBER	WHEN THE MOISTURE CONTENT OF THE WOOD (PER CENT) IS:	TEMPERATURE Dry Bulb	TEMPERATURE Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
1	over 40 use	180	173	85
	from 40-20 use	190	161	50
	20 and lower use	200	150	30
	Conditioning period use	200	195	90
2	over 35 use	180	173	85
	from 35-16 use	190	161	50
	16 and lower use	200	150	30
	Conditioning period use	200	195	90
3	over 35 use	180	173	85
	from 35-16 use	190	168	60
	16 and lower use	200	150	30
	Conditioning period use	200	195	90
4	over 30 use	180	173	85
	from 30-13 use	190	168	60
	13 and lower use	200	150	30
	Conditioning period use	200	195	90
5	over 40 use	160	154	85
	from 40-20 use	170	144	50
	20 and lower use	180	135	30
	Conditioning period use	180	175	90
6	over 35 use	160	154	85
	from 35-16 use	170	144	50
	16 and lower use	180	135	30
	Conditioning period use	180	175	90

SCHEDULE NUMBER	WHEN THE MOISTURE CONTENT OF THE WOOD (PER CENT) IS:	TEMPERATURE Dry Bulb	Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
7	over 30 use	160	154	85
	from 30-13 use	170	144	50
	13 and lower use	180	135	30
	Conditioning period use	180	175	90
8	over 30 use	160	154	85
	from 30-13 use	170	150	60
	13 and lower use	180	135	30
	Conditioning period use	180	175	90
9	over 25 use	160	154	85
	from 25-13 use	170	150	60
	13 and lower use	180	135	30
	Conditioning period use	180	175	90
10	over 50 use	120	108	65
	from 50-30 use	125	105	50
	" 30-20 use	135	107	40
	" 20-10 use	145	108	30
	10 and lower use	150	112	30
	Conditioning period use	150	146	90
11	over 50 use	115	103	65
	from 50-30 use	120	102	50
	" 30-20 use	130	105	40
	" 20-10 use	140	104	30
	10 and lower use	150	112	30
	Conditioning period use	150	146	90
12	over 40 use	160	141	60
	from 40-20 use	170	136	40
	20 and lower use	180	130	25
	Conditioning period use	180	175	90
13	over 40 use	140	132	80
	from 40-30 use	145	135	75
	" 30-25 use	150	137	70
	" 25-20 use	155	136	60
	" 20-15 use	160	135	50
	" 15-10 use	165	127	35
	10 and lower use	170	116	20
	Conditioning period use	170	165	90
14	over 40 use	135	128	80
	from 40-30 use	140	130	75
	" 30-25 use	145	133	70
	" 25-20 use	150	132	60
	" 20-15 use	155	131	50
	" 15-10 use	160	124	35
	10 and lower use	165	112	20
	Conditioning period use	165	161	90

SCHEDULE NUMBER	WHEN THE MOISTURE CONTENT OF THE WOOD (PER CENT) IS:	TEMPERATURE Dry Bulb	TEMPERATURE Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
15	over 40 use	130	123	80
	from 40-30 use	135	126	75
	" 30-25 use	140	128	70
	" 25-20 use	145	128	60
	" 20-15 use	150	127	50
	" 15-10 use	155	124	40
	10 and lower use	160	115	25
	Conditioning period use	160	156	90
16	over 40 use	125	118	80
	from 40-30 use	130	121	75
	" 30-25 use	135	123	70
	" 25-20 use	140	123	60
	" 20-15 use	145	122	50
	" 15-10 use	150	120	40
	10 and lower use	155	111	25
	Conditioning period use	155	151	90
17	over 40 use	110	107	90
	from 40-30 use	115	110	85
	" 30-25 use	120	113	80
	" 25-20 use	125	116	75
	" 20-15 use	130	116	65
	" 15-10 use	135	115	50
	" 10-8 use	140	108	35
	8 and lower use	145	108	30
	Conditioning period use	145	141	90
18	over 40 use	105	102	90
	from 40-30 use	110	105	85
	" 30-25 use	115	109	80
	" 25-20 use	120	111	75
	" 20-15 use	125	112	65
	" 15-10 use	130	109	50
	" 10-8 use	135	101	35
	8 and lower use	140	104	30
	Conditioning period use	140	136	90
19	over 40 use	125	123	95
	from 40-30 use	130	126	90
	" 30-25 use	135	129	85
	" 25-20 use	140	130	75
	" 20-15 use	145	130	65
	" 15-10 use	150	129	55
	" 10-8 use	155	123	40
	8 and lower use	160	119	30
	Conditioning period use	160	156	90

SCHEDULE NUMBER	WHEN THE MOISTURE CONTENT OF THE WOOD (PER CENT) IS:	TEMPERATURE Dry Bulb	Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
20	over 40 use	120	118	95
	from 40-30 use	125	122	90
	" 30-25 use	130	125	85
	" 25-20 use	135	125	75
	" 20-15 use	140	126	65
	" 15-10 use	145	125	55
	" 10-8 use	150	119	40
	8 and lower use	155	115	30
	Conditioning period use	155	151	90
	DRYING PERIOD, HOURS			
21	0-24	180	171	80
	24 to dry	190	148	35
	Estimated drying time: 48 to 60 hours.			
22	0-24	180	171	80
	24 to dry	190	155	45
	Estimated drying time: 54 to 66 hours.			
23	0-24	155	148	80
	24-48	165	148	62
	48 to dry	175	148	50
	Estimated drying time: 72 to 96 hours.			
24	0-24	150	144	85
	24-48	150	142	80
	48-72	155	140	65
	72 to dry	165	140	50
	Estimated drying time: 96 to 120 hours.			
25	0-8	150	146	90
	8-48	150	144	85
	48-72	160	144	65
	72 to dry	160	141	60
	Estimated drying time: 5 to 7 days.			
26	0-24	140	138	94
	24-72	150	146	90
	72 to dry	150	144	85
	Estimated drying time: 12 to 16 days to a moisture content of 18 to 20 per cent.			
27	0-6	160	156	90
	6-48	160	152	80
	48-72	170	152	64
	72-96	170	144	51
	96 to dry	175	142	43
	Estimated drying time: 108 to 144 hours to a moisture content of 8 per cent.			

SCHEDULE NUMBER	DRYING PERIOD, HOURS	TEMPERATURE Dry Bulb	Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
28	0-8	155	151	90
	8-48	155	147	80
	48-84	165	147	62
	84-108	170	144	51
	108 to dry	170	138	43
	Estimated drying time: 120 to 168 hours to a moisture content of 8 per cent.			
29	0-24	150	144	85
	24 to dry	150	139	75
	Estimated drying time: 48 to 54 hours to a moisture content of 18 to 20 per cent.			
30	0-24	150	144	85
	24 to dry	160	149	75
	Estimated drying time: 60 to 72 hours to a moisture content of 18 to 20 per cent.			
31	Throughout run	125	114	70
32	0-30	170	153	65
	30-54	180	152	50
	54-78	190	152	39
	78 to dry	190	140	28
	Estimated drying time: 4½ to 6 days to a moisture content of 7 per cent, 5 to 7 days to a moisture content of 5 per cent.			
33	0-48	150	135	65
	48-72	160	135	51
	72-96	170	135	39
	96 to dry	170	125	28
	Estimated drying time: 10 days to a moisture content of 10 per cent. An initial humidity higher than 65 per cent should not be used with western red cedar, since this wood tends to become soggy at high humidities. For western red cedar susceptible to collapse, the dry bulb temperature should be kept at 140°F. until the fibre saturation point is reached, after which the normal temperatures may be followed.			
34	0-4	160	158	95
	4-24	130	118	66
	24-48	140	122	58
	48-72	150	126	50
	72 to dry	150	122	43
	Conditioning if necessary	160	152	81
	Estimated drying time: 84 to 120 hours.			
35	0-24	170	161	80
	24-96	170	156	70
	96-144	170	147	55
	144 to dry	170	140	45
	Estimated drying time: 7 to 11 days to a moisture content of 6 per cent.			

SCHEDULE NUMBER	DRYING PERIOD, HOURS	TEMPERATURE Dry Bulb	TEMPERATURE Wet Bulb	RELATIVE HUMIDITY
		°F.	°F.	P.C.
36	0-24	165	148	64
	24-48	168	148	60
	48 to dry	170	148	57
	Estimated drying time: 96 hours to a moisture content of 8 per cent.			
37	0-24	150	144	85
	24-72	150	142	80
	72-168	150	138	72
	168 to dry	160	138	57
	Estimated drying time: 1″ clears 5 to 6 days, 2″ clears 9 to 10 days, to a moisture content of 14 per cent.			
38	0-24	150	147	92
	24-48	150	145	87
	48-96	150	143	82
	96-120	150	140	76
	120-144	150	138	72
	144 to dry	150	136	68
	Estimated drying time: 12 days to a moisture content of 12 per cent.			
39	0-24	160	157	93
	24-72	160	154	86
	72-105	160	151	79
	105 to dry	160	146	69
	Estimated drying time: 144 hours to a moisture content of 13 per cent.			
40	0-48	160	154	86
	48 to dry	160	150	77
	Estimated drying time: 1″ stock 60 to 72 hours, 2″ stock 96 hours, to a moisture content of 15 per cent. To obtain lower final moisture contents, use a dry bulb temperature of 160°F. and a wet bulb temperature of 130°F. after 72 hours.			

The following schedules, nos. 41, 42, and 43, are, at time of writing, still in the experimental stage, hence the inclusion of the ranges of moisture content.

SCHEDULE NUMBER	RANGE OF MOISTURE CONTENT (Per Cent)	DRYING PERIOD HOURS	TEMPERATURE Dry Bulb	TEMPERATURE Wet Bulb	RELATIVE HUMIDITY
			°F.	°F.	P.C.
41	over 45	0-180	170	166	90
	45-40	180-204	175	167	83
	40-30	204-216	180	170	79
	30-20	216-228	185	172	75
	20 to dry	228 to dry	190	168	60
	Estimated drying time: 11 to 12 days to a moisture content of 7 per cent.				
42	over 40	0-24	150	138	72
	40-35	24-36	155	136	59
	35-25	36-60	165	139	50
	25 to dry	60-92	175	140	40
	Recondition at 8 per cent	92-98	175	166	80
	Estimated drying time: 96 hours to a moisture content of 8 per cent.				
43	over 40		150	140	76
	40-30		155	140	66
	30-25		160	140	58
	25-20		165	140	51
	20-15		170	140	45
	15-10		175	140	40
	10 to dry		180	140	35
	Recondition at 7 per cent		180	168	75
	Estimated drying time: 10 to 12 days to a moisture content of 7 per cent.				

STORAGE AND SHIPMENT OF LUMBER

Green lumber which has been piled on kiln trucks in preparation for kiln-drying should be protected from the elements to reduce checking and splitting. Covered storage is generally recommended for this purpose, although coverings for the ends of the piles will assist in reducing checking at this point. Kiln-dried lumber should be piled in storage sheds in which temperature and relative humidity conditions are so maintained that the stock is held at a moisture content consistent with that which it would acquire in use. This is not always possible, and a compromise may be made by bulk-piling it in open storage sheds. This method only protects the lumber from the rain and not from atmospheric changes. The inner tiers of the lumber will retain a low moisture content for some time but will eventually reabsorb moisture consistent with the equilibrium moisture content of the surrounding atmosphere.

Lumber which has been kiln-dried to a low moisture content may be expected to reach its destination in satisfactory condition when shipped by rail, if it is close-piled in closed freight cars and not exposed to rain or extremely moist conditions.

SPECIAL METHODS OF SEASONING WOOD

Several special methods have been considered from time to time as offering a quick method of seasoning lumber, such as the following:

(1) Chemical seasoning.
(2) High-frequency dielectric heating.
(3) Infra-red radiation.
(4) Solvent seasoning.
(5) Vacuum drying.
(6) Vapour drying.

Chemical Seasoning

Chemical seasoning consists in applying a hygroscopic chemical to green wood, either in the form of a liquid or powder, and following this treatment with kiln-drying or air-seasoning.

The hygroscopic chemical retains moisture at the surface of the lumber and tends to reduce the amount of checking which might occur. Chemical seasoning in itself does not necessarily decrease the drying time, but permits the use of a more severe drying schedule.

Various chemicals have been used in chemical seasoning. Common salt is probably the most effective in reducing checking, but since it corrodes metals it may damage machinery, and for this reason it is not favoured. Crystal urea is generally used for treating Douglas fir, but is not reliable with some other species.

High-frequency Dielectric Heating

The results of laboratory tests showed that seasoning by dielectric heating is technically possible in most cases. However, a study of the economics of the process indicated that the cost of drying large quantities of lumber from a green condition would be prohibitive. The process may have merit in the final drying, below the fibre saturation point of impervious woods which are extremely difficult to season by other methods. It is also felt that this method of drying may prove advantageous for the seasoning of small dimension stock for special products.

Infra-red Radiation

The use of infra-red lamps for seasoning wood has been considered, but since wood acts as an insulator, the radiated heat from this source penetrates the wood only slightly in the time necessary to bring the surface of the wood to the desired temperature for drying. Continued heating to force the heat into the interior of the wood will raise the temperature at the surface sufficiently to cause de-grade. Also, in contrast to normal kiln-drying practice, where the hot air circulates through the pile, infrared radiation heats only the boards which are directly exposed to it. It is in limited use for drying veneers.

Solvent Seasoning

Solvent seasoning consists in immersing the wood in a solvent which is maintained at a temperature in excess of the boiling point of water, thus causing the water in the wood to boil off.

This process was developed by the Western Pine Association in attempting (1) to increase the grade of pitchy lumber by removing resin pitch and other extractives and (2) to remove the moisture. The process is reported to be quite efficient and rapid, but requires special and expensive equipment.

Vacuum Drying

Vacuum drying consists in placing the wood to be dried in a closed chamber and heating it in a vacuum. Since water evaporates at a comparatively low temperature when in a vacuum, this characteristic assists in withdrawing the moisture from the wood. However, there is difficulty in applying heat and for this reason it is only used in preparing wood for preservative treatment, where a low moisture content is not necessary.

Vapour Drying

Vapour drying consists in exposing the wood to the vapours produced by boiling an organic chemical. Since this process is carried out at a temperature of approximately 300°F., the moisture is removed from the wood and passes off with the chemical vapours. These vapours are drawn off and condensed. The water separates out and the chemical is re-circulated.

This process has been patented and has only been used in partially drying timbers previous to applying a preservative treatment.

SEASONING DEFECTS

Types

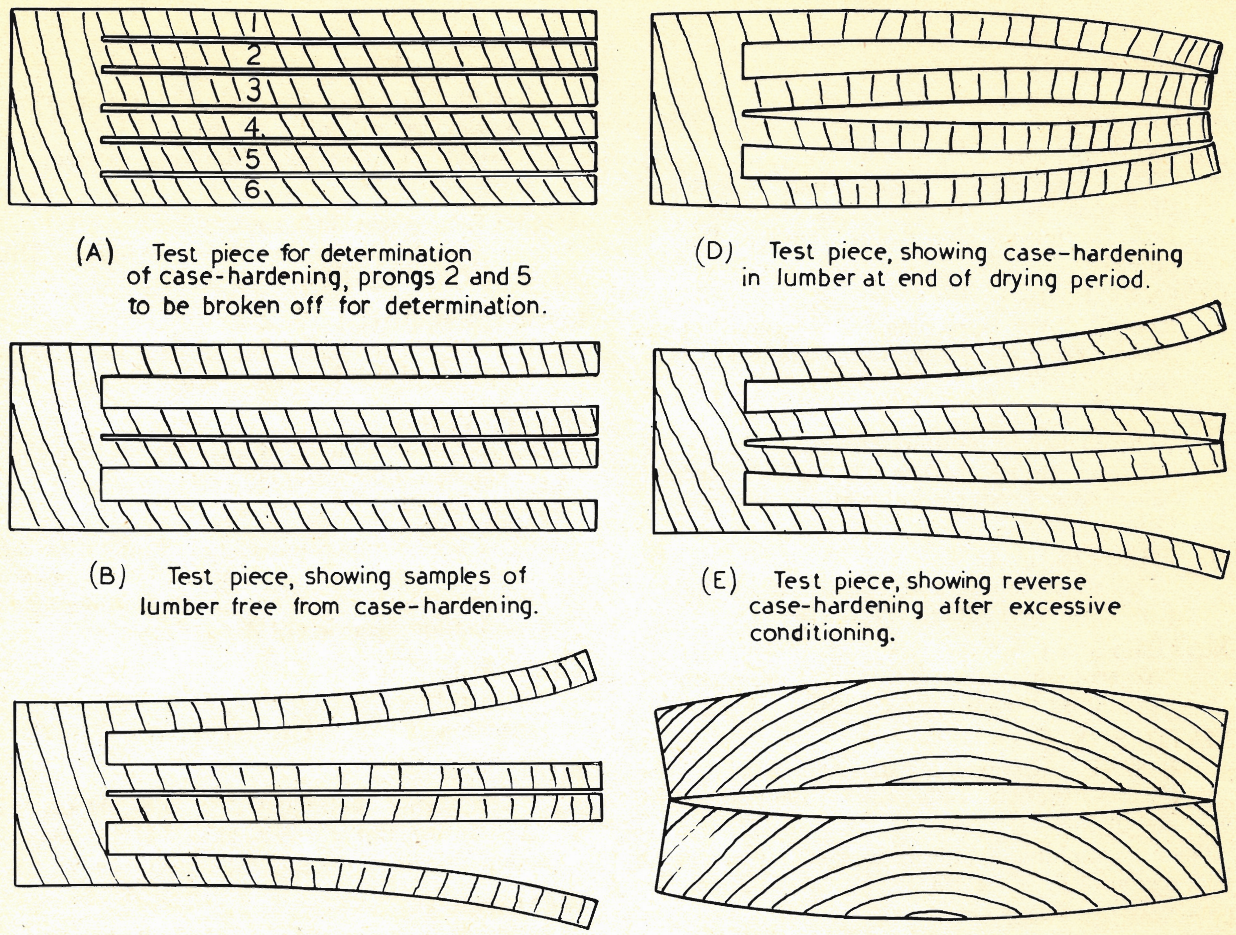
Seasoning defects may be classified, roughly, into four types which depend on the nature of the cause of the defects, as listed below.

(1) Defects caused by uneven shrinkage.
(2) Defects caused by fungus.
(3) Defects caused by chemical action.
(4) Defects caused by physical characteristics.

Defects Caused by Uneven Shrinkage

Several defects are caused by uneven shrinkage of the lumber, such as case-hardening, checking and splitting, warping, honeycombing, collapse, and loose knots. Most of these are due to improper seasoning methods.

Case-hardening occurs when the surface dries too quickly in comparison with the drying of the interior. This sets up stresses in the wood which may cause splitting or warping, and possible damage to the finished product. Case-hardening is indicated by testing a one-inch section of lumber cut at least two feet from the end of the piece and notched as shown in sketch (a) Figure 26. No case-hardening is in-



(A) Test piece for determination of case-hardening, prongs 2 and 5 to be broken off for determination.

(D) Test piece, showing case-hardening in lumber at end of drying period.

(B) Test piece, showing samples of lumber free from case-hardening.

(E) Test piece, showing reverse case-hardening after excessive conditioning.

(C) Test piece, showing case-hardening in lumber partially dry.

(F) Cupping of case-hardened lumber after resawing.

FIGURE 26.—Case-hardening Test Pieces.

dicated when the prongs remain straight, as illustrated in sketch (b). Varieties of case-hardening are shown in sketches (c) and (d). Case-hardening, as illustrated in sketch (d), should be relieved by subjecting the lumber to high humidities before it is manufactured. If the relieving period is too long, reverse case-hardening may occur, as illustrated in sketch (e). Sketch (f) shows cupping of case-hardened lumber after resawing.

Other forms of defects caused by uneven shrinkage may arise from improper seasoning methods.

Defects Caused by Fungus

These are discussed in Chapter 6; Decay and Stains in Wood.

Defects Caused by Chemical Action

Several defects occur from this cause, such as mineral stain, coffee stain, yard brown-stain, kiln-burn, water stain, and dip stain. In seasoning white pine, yard brown-stain and kiln-burn may be particularly troublesome in the heartwood, and special care is necessary to prevent them.

Defects Caused by Physical Characteristics

Irregular moisture content and resin streaks or pockets are the chief causes of these defects. In some instances, irregular moisture content may be caused by a drying period which is too short. In other instances, such as occur in drying white pine, pieces with high moisture content occasionally are encountered. This is typical of white pine and western red cedar from some sections, and can only be cured by putting the pieces aside and re-drying them in the next charge.

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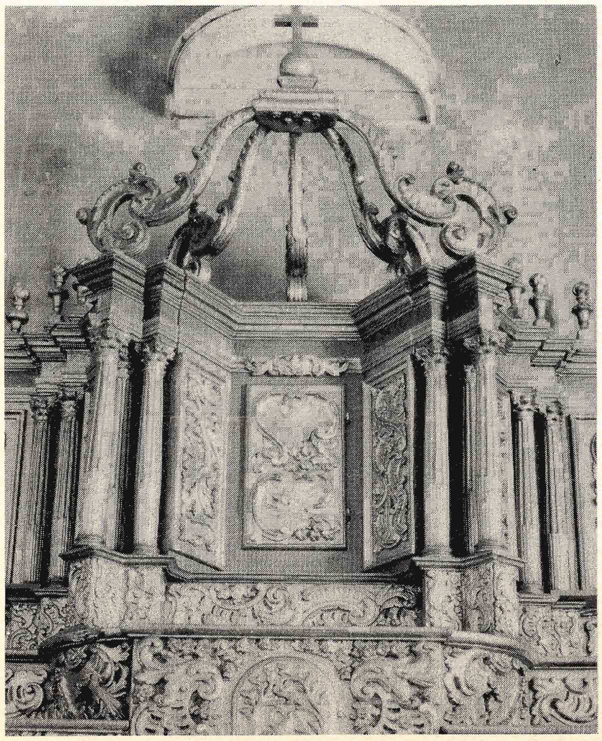
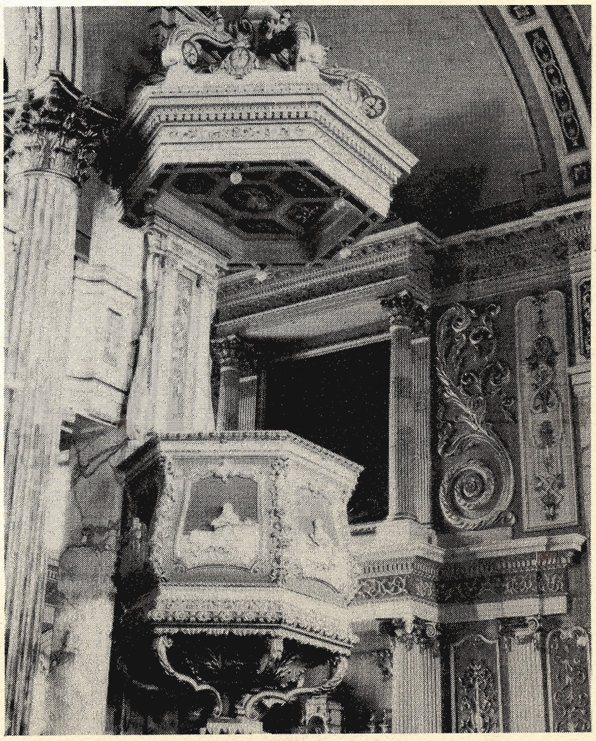
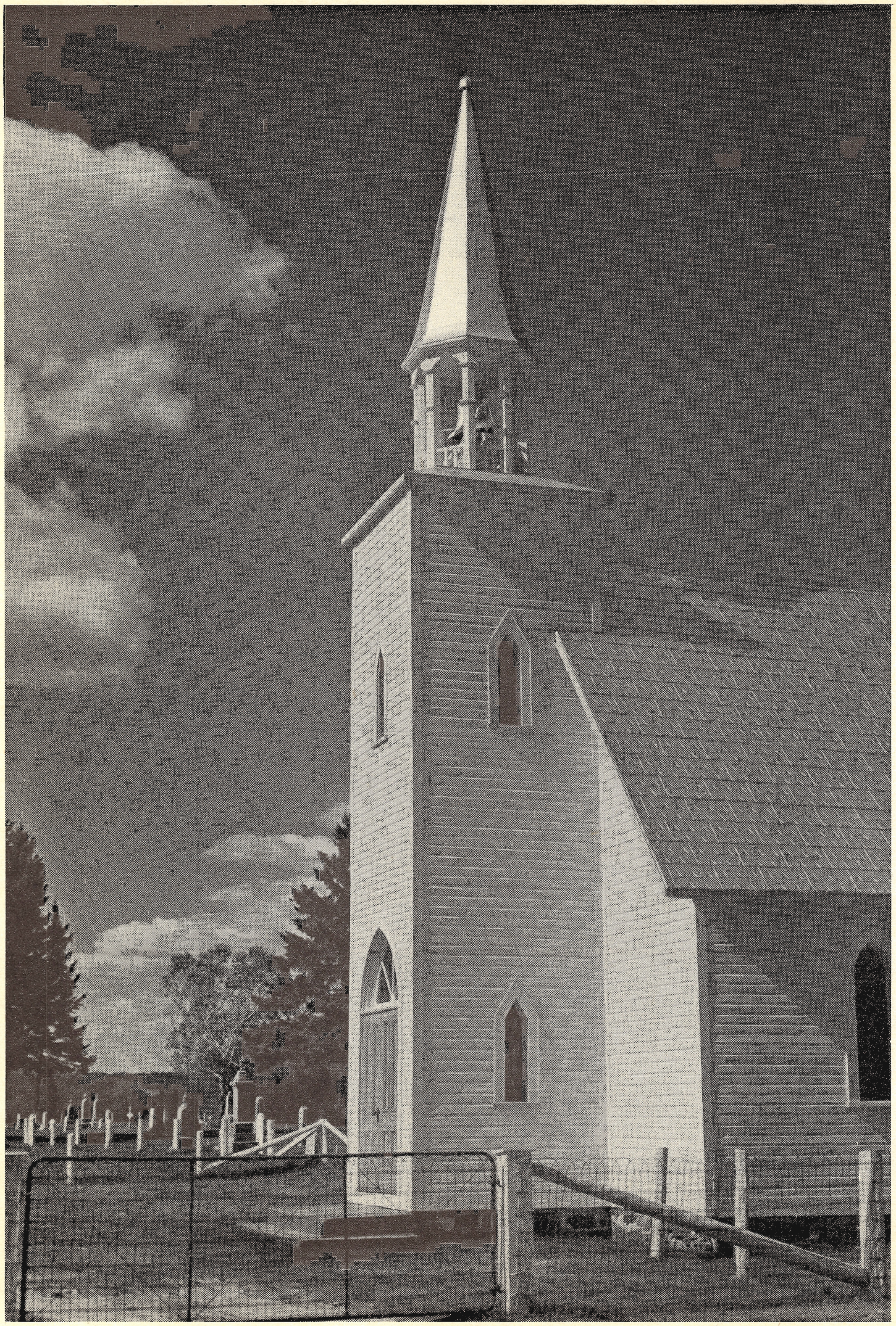




Tabernacle, The Seminary, Quebec, and Pulpit and Carved Ornament, Church of Saint Denis, Montreal. The old churches of Quebec enshrine a wealth of superb craftsmanship in wood.



A Country Church, Poltimore, Que.

DECAY AND STAINS IN WOOD

by C. W. FRITZ

DECAY

Cause

THE disintegration of wood known as decay is caused by the growth of fungi in the wood tissues. Fungi, of which the bread mould is a well-known and common example, are plants of simple structure. The plant body consists of minute branching tubes called hyphae, which in mass are known as the mycelium (Plate 53). In the case of wood-inhabiting fungi these tiny tubes spread through the wood, penetrating and disintegrating the cell walls, and thus reducing the strength of the wood (Plate 54).

Dissemination of Fungi

Wood-destroying fungi develop within wood and at maturity produce their fruit-bodies on the surface. These fruit-bodies are the best-known parts of fungous plants. They appear only on wood which is in an advanced stage of decay, and are in the form of toadstools, fleshy or woody shelves, or encrusting sheets (Plates 59, 60, 68). At maturity, fungous fruit-bodies shed clouds of fine dust-like particles known as spores (Plate 55), which function as do the seeds of higher plants. The spores are microscopic in size, and, carried by air currents or other agencies, they are scattered far and wide. These spores, if they fall on a moist wood surface and meet other favourable growth conditions, are capable of developing and producing new fungous plants. Thus disease is spread from one piece of wood to another without contact between sound and infected material: the space is bridged by the dispersal of spores.

In germination, the spores produce minute tubular growths which penetrate the wood tissues. These elongate, branch, and finally ramify throughout the wood, feeding upon the wood tissues, and thereby effecting the development of the type of rot characteristic of the fungus by which the spores were produced. When the fungus is well established in the wood, fruit-bodies are produced on the surface, spores are shed, and the growth cycle is repeated.

If infected wood is placed in contact with sound lumber, disease may be communicated to the sound material without the production of spores. In a moist situation the fungous threads in the diseased material simply elongate and penetrate the sound wood, and by their active growth soon reduce its value.

Growth Requirements of Wood-inhabiting Fungi

Fungi, in common with other members of the plant kingdom to which they belong, require for their development food, air, moisture, and suitable conditions of temperature.

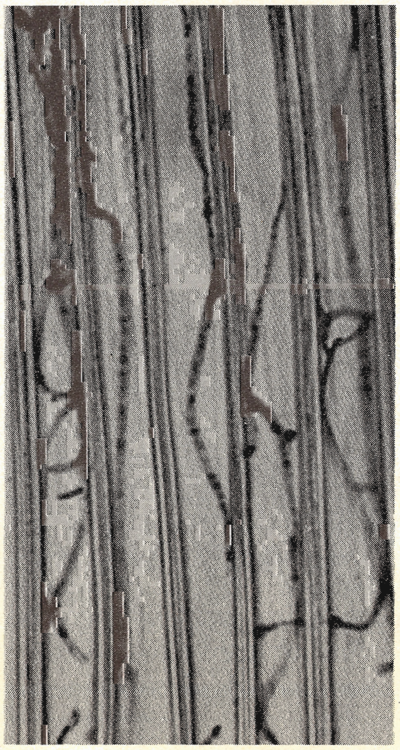
Food.—Wood-inhabiting fungi find food suitable for their requirements in the cellulose, lignin, and other chemical components of the cell walls and food reserves contained in the wood tissues. No species of wood is entirely immune from attack, if placed under conditions favourable to the growth of fungi. There is much variation in the susceptibility of different

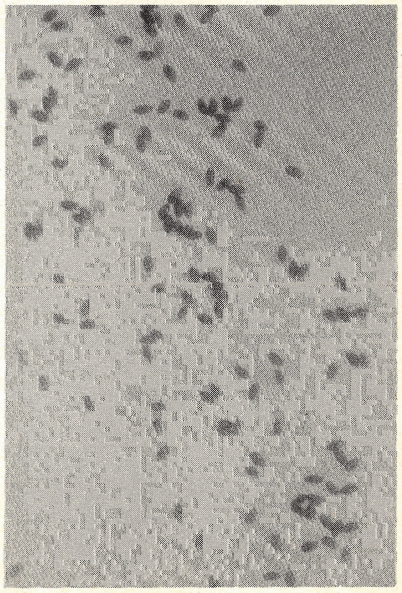
species to decay; but all will furnish food for one or more species of fungi, and can, therefore, be reduced by fungal action.

Air.—As far as our present knowledge goes, it may be stated that all wood-destroying fungi require free oxygen in order to maintain life. If the air supply in a piece of infected wood is removed by saturation of the wood with water, or is sufficiently contaminated by the introduction of toxic gases, the fungi will eventually die.

Moisture.—In order to grow, all wood-inhabiting fungi must be provided with a moderate amount of water. It is generally recognized that wood in an air-dry condition is immune from fungal attack. Fungi growing in wood do not necessarily die when sufficient moisture is removed to render it air-dry, but they cease active growth. They may remain in a dormant state for years, if this condition is maintained; if sufficient moisture is subsequently supplied, they may then revive and continue their work of destruction.

Air-moisture Balance.—The space within a piece of wood not occupied by wood substance, that is, by cell walls and food reserves, is normally filled with air and water. In contact with an adequate supply of moisture, wood substance will absorb water until it is saturated; and, if an excess over this amount is present, it will remain as free water in the cell cavities. As the water content is increased, air is driven out, and as wood dries, air enters the cells. The air-water balance changes continually in response to changing atmospheric conditions, and is one of the most important factors controlling the susceptibility of wood to decay. It has been determined that wood substance has a specific gravity of approximately 1.56, and that it will absorb water to the amount of 55 per cent of its volume. A piece of dense wood with a moisture content of 100 per cent, based on the oven-dry weight of the wood, will, therefore, contain much more water than the same volume of a less dense wood containing the same percentage of moisture. The space available for air in the former is reduced in comparison with that in the latter by excess of both wood substance and water; and for that reason alone the dense wood may be much less susceptible to fungal attack than is the less dense. Tests of the growth of both staining fungi and wood-destroying fungi indicate that in wood below fibre-saturation point fungal growth is likely to be slight or to fail entirely. In blocks of pine,





Left: PLATE 53.—Mycelium, (× 250).

Centre: PLATE 54.—Mycelium in Wood, (× 350).

Above: PLATE 55.—Spores of Fungus, (× 250).

Münch found that staining was greatest when the moisture content was between 33 per cent and 74 per cent (based on the oven-dry weight of the wood); little penetration occurred in wood of 28 per cent moisture content or within the range of 78 per cent to 119 per cent, and it failed entirely at 143 per cent. Snell (18) made tests using loblolly pine sapwood of specific gravity 0.44 and Sitka spruce of specific gravity 0.35. In the former, decay was most rapid when the moisture content was between 49 per cent and 72 per cent, and failed when it reached 150 per cent; in the latter, optimum conditions for decay were provided by a moisture content of 43 per cent to 133 per cent, and decay ceased when the moisture content reached 203 per cent. It may be said, therefore, that decay and stain may develop in wood with a moisture content somewhat below fibre-saturation point, and advance rapidly as the moisture content is increased, until an insufficient air-content acts as a limiting factor. The upper limit of the moisture-content percentage which will permit growth is dependent upon the density of the wood.

Temperature.—Wood-destroying fungi find favourable conditions for growth in the open during the season when trees and other plants are in active growth. They withstand the cold of winter in a dormant state, and, with the coming of spring, recommence their growth activities. Under experimental conditions in the laboratory, it has been found that these fungi show some variation in their responses to changes in temperature. All that have been tested, however, become inactive as the temperature approaches freezing, and find optimum growth conditions at points ranging between 65°F. and 95°F.; growth becomes less rapid as the temperature is increased, and ceases between 104°F. and 115°F.

Effect on the Sale and Utility of Wood

The development of decay affects both the physical and chemical properties of wood, and thus alters it to such an extent that decayed wood cannot serve the same purposes as sound material of the same dimensions. In the initial stages of decay, slight colour changes are noted, and as disintegration proceeds these changes are accentuated. The discolorations differ according to the species of wood attacked and the fungus causing the disease. If the stain is unsightly, it excludes the wood from use in situations in which, from an aesthetic standpoint, colour is a governing factor, as in the manufacture of furniture or interior trim, and may thereby cause such de-grade that serious monetary losses result.

Wood is greatly reduced in strength as rot develops; even incipient decay may cause serious weakening of the wood. For that reason, the presence of rot precludes the use of infected material in all situations in which maximum strength is required. Thus, timbers for beams, joists, and all supporting structures are reduced in value by the presence of decay. Timbers containing fungal infection are sometimes used; but the distribution, amount, and type of rot in the wood must be taken into account in calculating the mechanical strength to be expected from them. Such timbers should never be used where conditions are such as to permit the further development of the fungi present.

Chemical changes in wood affect its utilization in the manufacture of pulp, paper, rayon, and similar products. In feeding upon the wood tissues, fungi, by means of secretions from the mycelium, dissolve the components of the walls and contents of the wood cells. Some decomposition products are absorbed by the fungi and used in their growth processes. In the manufacture of groundwood, in which the wood fibres are mechanically separated, and used unaltered, a smaller yield of pulp is obtained from wood in which fibres have been destroyed by decay than from an equal volume of sound material, while wood in which fibres have been merely weakened by fungal attack produces pulp of reduced strength. In the manufacture of paper, rayon, etc., reduction in yield, as well as discoloration and weakening of the product, are often experienced if badly infected wood is used.

Distribution of Decay

All organic material in warm, moist situations is subject to the attack of fungi, and the agents of decay may establish themselves even in the standing tree. The heartwood of standing, living timber is particularly susceptible to attack, owing to the abundance of air present in its cells. Fungi enter the heartwood by means of the germination of spores in situations from which the mycelium is able to penetrate its tissues. Such channels of infection are provided by branch stubs, broken tops, and wounds along the trunk or roots. Conditions vary in these different situations, and the variations afford access

to different species of fungi. Top rots, trunk rots, and butt rots are likely to differ in type, but some fungi are capable of destroying the entire heartwood. Butt rots are usually confined to four or five feet at the base of the tree; but, apart from the slight amount of cull thus caused by their development, they are responsible for extensive losses of timber, owing to the fact that the reduction in strength caused by their presence is a contributory factor to wind-throw. Sapwood in healthy condition in the living tree is unlikely to suffer from the attack of wood-destroying fungi; but a reduction in water content due to drought, root injury, or other adverse factor may render the wood susceptible to infection. Münch, by laboratory tests of the growth of many fungi on young twigs which had been collected in winter condition, showed that penetration was rapid when the twigs were maintained at the moisture content obtaining in the open during that season; transpiring twigs, however, owing to the increase in water content, resisted infection. This applied to the water-conducting tissues and not to older wood in the interior of the stems, in which the air supply was not reduced.

The felling of timber lays the wood open to the attack of many fungi which are unable to infect living trees; it also provides conditions in which some of the fungi already established in infected trees are able to develop rapidly and to mature their fruit-bodies. Trees felled in early summer, and allowed to lie in the woods until the logs are made and removed during the winter season, gradually dry to a moisture content which renders them very susceptible to decay. The sapwood is rapidly attacked, and decay may penetrate a foot or more from cut surfaces in the course of a few weeks. Birch is extremely non-resistant in such situations, but no species is immune if temperature and moisture combine to favour fungal attack.

Manufactured lumber in seasoning yards will decay unless piled in such a way that the moisture content is reduced to a point inhibitory to fungal growth; moreover, ventilation in the piles must be adequate to prevent subsequent re-absorption of moisture. Rots initiated in the standing tree or in the log may continue development in the lumber. Indeed, fungal fruit-bodies have been noted growing in the yards from decayed portions of boards in which the rot had started during storage of the logs in the forest. In addition, lumber sound when manufactured may, owing to improper storage conditions, pick up disease in the seasoning yards, since fungi capable of infecting the wood are always present in abundance.

Untreated wood is durable in service only under conditions which do not permit the growth of fungi. In lumber journals, attention is often called to the fact that wooden water-pipes laid fifty or a hundred years ago have been found thoroughly sound when taken up, or that submerged piling of certain species has given eighty or ninety years of service. Such facts should occasion no surprise; the piles which formed foundations of the houses of lake-dwellers of pre-historic times have stood throughout the ages and remain today. The durability of the wood is not due to specific inherent characteristics, but to the fact that fungi cannot grow in wood so saturated with water as to exclude the free oxygen which they require to maintain life. On the other hand, the furniture in our houses does not rot, because it is dry; and for the same reason wood from the tombs of the ancient Egyptians has withstood the ages and frequently remains sound at the present day. It is in situations in which moisture collects and air is available that untreated wood is unsatisfactory for permanent construction. Thus, fence-posts and telephone poles decay at the ground-line; railway ties fail after a few years' service; joists rot when faulty construction permits the absorption of moisture; floors laid on moist concrete decay rapidly; and roofs insufficiently insulated from the cold outer air rot, if the air within the building is sufficiently humid to permit condensation of water, which may be absorbed by the wood.

Wood products are also subject to decay; thus pulp, both groundwood and chemical, rots rapidly if stored under moist conditions. In the manufacture of chemical pulp, wood-destroying fungi present are killed, and Kress reported indications that grinding for the production of groundwood pulp has a sterilizing effect on infected wood (13). Subsequent infection during or after manufacture is, however, frequent; and losses due to improper storage of the manufactured product are often considerable.

Identification of Specific Cases of Decay

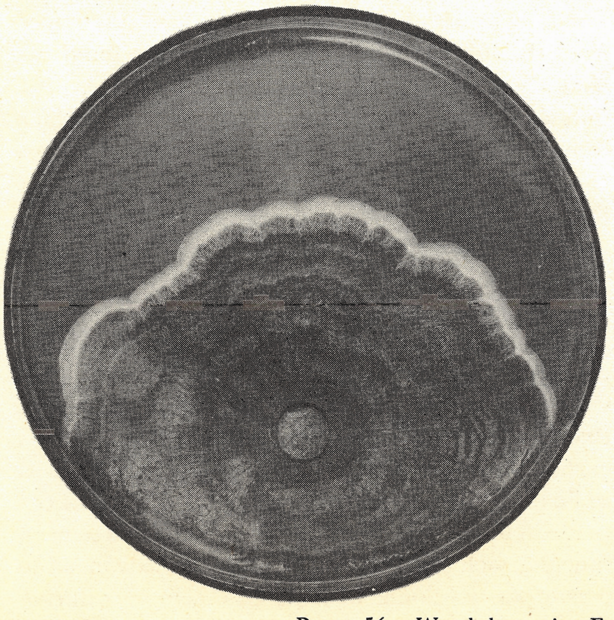
Decay may be identified with moderate certainty if a fungal fruit-body is found attached to the surface of a piece of wood in the immediate vicinity of the

rotted area. The fruit-bodies have been studied, and their distinguishing characteristics have been made the basis of a classification, by means of which identification is possible. Sometimes more than one wood-destroying fungus is active in the same area of rot; and cases are on record where two well-known fungi have developed from the same tiny fragment removed from rotted wood by a method described below in reference to the isolation in culture of the fungus causing decay. Such cases are, however, uncommon; and for practical purposes it is safe to assume that, if the fruit-body of a wood-destroying fungus is growing from a piece of wood, that fungus is responsible for the decay extending inward from the point of attachment (Plates 64 and 69).

When no fruit-body is present, a study of the rot itself may permit diagnosis, since the rots produced by many fungi are sufficiently characteristic to permit identification of the fungus which has caused the decay. The obvious features, such as colour changes, fracturing, and texture of the wood, assist in diagnosis; the microscopic appearance of the cells of the rotted wood, the type of mycelium, and the manner in which it penetrates and disintegrates the cell walls are further aids. Detailed studies of these microscopic characteristics of many rots are reported by Hubert (8).

If specific determination of the rot in any sample submitted cannot be made by visual examination of the specimen, it is often possible by a cultural study to identify the fungus present. It has been found that if a fragment of the tissue of a fungal fruit-body is removed with sterilized instruments under aseptic conditions, and transferred to a nutrient jelly which has been prepared and sterilized in a glass culture tube, mycelium will develop on the surface. For routine work, a jelly which provides a satisfactory food supply for most wood-destroying fungi is made with malt extract diluted with distilled water and solidified with agar-agar. The mat of mycelium varies according to the species of fungus; among the characteristics of value in distinguishing different species are colour, rate and manner of growth, and texture. It has been shown that the characteristics of these cultures are sufficiently constant and distinct to permit identification of the fungi from which they were made*. Therefore, at laboratories where wood-destroying fungi are under study, a set of standard cultures is kept for reference. Such cultures can be kept indefinitely by transferring every four or five months a fragment of the mycelium of each to a fresh tube of jelly; the mycelium continues its growth on the new surface and produces a mat similar to the original.

It has also been shown that a similar mat can be obtained from a fragment of rotted wood. A small piece of the infected wood from one-eighth to one-quarter of an inch square is removed, as in the case



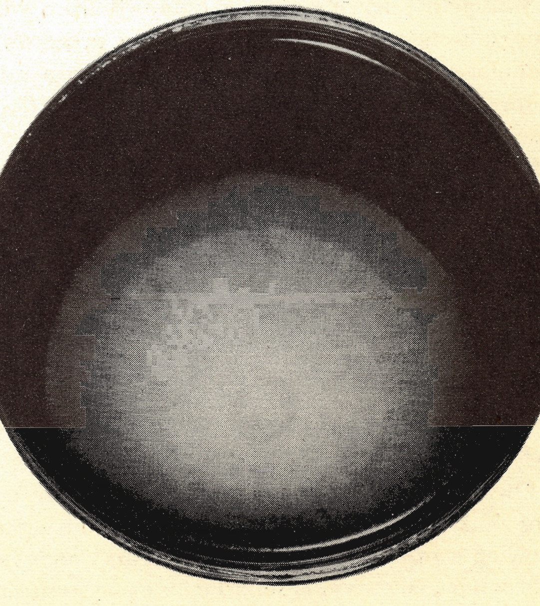


PLATE 56.—Wood-destroying Fungi Growing on Malt Extract Jelly.

*Cultural Criteria for the Distinction of Wood-destroying Fungi, Clara W. Fritz, Royal Soc. Can., Trans. V:1923: pp 191-288: pl.

of the tissue of the fruit-body, and partly embedded in malt-agar jelly in a culture tube. If living fungus is present in the wood, the mycelium will grow out and form a mat similar to that produced by fruit-body tissue. Therefore, if it is impossible to identify by visual examination of the wood the fungus present in any rot, such a culture is made, and compared with standard fruit-body cultures. If it agrees with any of these, its identity is established.

In a majority of cases, specific identification of the fungus responsible for decay is quite unnecessary. If a fence-post rots, or a railway tie fails in service, determination of the particular fungus which caused disintegration of the wood may be a question of purely academic interest. But instances are not infrequent in which the studies outlined above are of very practical value. If identification of a fungus establishes the conditions under which infection of the wood occurred, a way is opened for exclusion of the rot from commercial timber. Thus the presence of a fungus which develops only in the standing tree indicates the need for more careful inspection of timber at the point of origin; on the other hand, fungi which develop after the tree is felled can be eliminated by sanitary methods of handling.

Conditions Affecting the Service Life of Wood

Season of Felling

Satisfactory service can be obtained from wood only if it is handled throughout the processes of manufacture by methods which reduce to a minimum the activities of wood-destroying fungi. Given a sound standing tree, the first question to be considered is the season at which it should be felled in order to ensure maximum durability of the timber produced. In this connection, three factors have at different times been made the basis of recommendations for the season of felling, namely, seasonal changes in the moisture content of wood in the standing tree, chemical and physical changes in wood substance due to season, and differences in the environmental conditions to which the felled wood is subjected at different seasons.

Owing to the prevalent idea that moisture content of a tree is lower in winter than during the growing season, the opinion was for years widely held that winter-cut wood is superior in decay-resistance to that felled in summer. But, as it became recognized that there is not a reduction of moisture content in the wood of trees in winter condition, this view changed, and the view was accepted that the time of cutting has very little effect upon the durability or other properties, if the timber is properly cared for after it is cut.

The opinion has also been voiced that winter-cut wood is more durable than summer-cut, owing to differences in chemical composition. This statement was made on theoretical grounds and has been confirmed for certain species by extensive experimental work carried out in Switzerland by Gäumann (6). These tests indicate that spruce and fir exhibit an annual cycle of resistance which parallels the growth cycle; the wood is most susceptible to attack by fungi if felled during the period of greatest interchange of material in the tree. The variation affects both sapwood and heartwood, the latter, however, in slighter degree. Storage under cover decreased susceptibility to fungal attack in both species; and the decrease was much greater in summer-felled than in winter-felled wood. One year's seasoning under cover tended to obliterate differences shown by wood felled at different seasons. Too much stress, therefore, must not be placed on the influence of time of felling on durability; it is significant only when green wood is exposed to infection.

Wood felled in summer is immediately exposed to the attack of the wood-destroying fungi abundant and active in the forest at that season. Winter-felled wood, which dries out to some extent and is removed from the forest before the activity of the fungi becomes a serious problem, escapes this danger. The unfavourable environmental conditions to which summer-cut wood is exposed can, however, be overcome by proper handling of the felled trees, since they do not affect the inherent durability of the wood at the time of cutting.

Storage of Logs

After the tree is felled, the next question is the proper treatment of the logs into which it is converted. The essential point to be kept in mind is that the logs should be delivered at the mill at the earliest possible moment; the longer they are allowed to lie in the woods, the greater the loss will be. Logs made in winter from winter-cut timber are free from fungal attack until spring is sufficiently advanced to permit the development of fungi; if held over during the late spring and summer months, these logs deteriorate. The practice occasionally adopted by

hardwood manufacturers of felling trees in summer and leaving them with the foliage on until they are converted to logs in the autumn or winter leaves the timber, with a gradually decreasing moisture content, exposed to infection during the period of greatest fungal activity; as a result, serious loss may be experienced.

Barking logs decreases their susceptibility to decay, since it hastens the escape of moisture. Storage in dry situations, if it does not lead to serious checking owing to a too rapid decrease in moisture, will prove advantageous, since it retards the development of fungi. Immersion in water protects logs from decay; but floating them in ponds leaves the wood above water open to attack. Logs subjected to alternate wetting and drying deteriorate rapidly.

Coating the ends of logs with certain toxic chemicals (19) has been found useful in preventing the development of stain, decay, and end-checking, and might possibly prove beneficial in the case of logs held over in the woods or yards under unfavourable storage conditions. The development of efficient end-coatings is a problem at present under study.

Transport of Logs

Logs are transported both overland and by water. In the former case delivery is rapid and the loss due to decay is, therefore, negligible. But in Canada water is a common means of transport, the drives lasting from a few weeks to upwards of three years; and logs held up in jams or along the shores may be even longer on the journey to the mill. The longer the drive, the greater the opportunity for deterioration, since all along the route conditions may be favourable to the development of rot.

Storage of Lumber

After manufacture, lumber is immediately stacked in yards for seasoning and storage, or is kiln-dried and stored. Kiln-drying sterilizes the lumber (7), and reduces the moisture content to a point at which infection cannot occur. If the lumber is then stored in dry sheds, where it does not pick up moisture, it remains immune to infection. If, however, it is exposed to the weather or stored in a damp situation, it rapidly absorbs moisture, and is soon in a condition in which infection is again possible.

PLATE 57.—Insanitary Conditions in Lumber-seasoning Yard.

Green lumber stacked in the seasoning yard is very susceptible to fungal attack. Two points to be kept in mind with regard to protection of the lumber are that wood should always be stored under clean, sanitary conditions, and the moisture content should be reduced as rapidly as is consistent with the prevention of other seasoning defects. The latter subject is discussed in detail in Chapter 5. With regard to the former, it should be remembered that any diseased wood retained in a lumber yard is a source of danger to sound stock piled in the vicinity. Common practices, detrimental to the production of sound lumber, which have been noted in seasoning yards are the use of (a) sawdust and mill refuse in the yard bottom, (b) diseased foundation and construction timbers, (c) infected crossers, (d) piles of lumber discarded or set aside owing to stain or decay, (e) wood debris left in the vicinity of lumber in the process of seasoning. Sound wood may become infected by contact with diseased wood or by fungus spores. Conditions represented in Plates 57 to 60 should, therefore, be avoided. Concrete piers are the most satisfactory supports for pile foundations; if wood is used it should be treated with a suitable preservative. All permanent construction timbers in the yard should be similarly treated.

Unseasoned lumber close-piled for shipment by rail or water is often attacked by stain or decay during transit. Stacked in a car or the hold of a ship, in which the stagnant air soon becomes moist owing to the evaporation of water from the wood, such lumber is placed in conditions very conducive to the development of fungi. Long voyages under such conditions may entail very serious losses, especially in the case of species particularly susceptible to infection. Seasoned lumber should not be permitted to pick up moisture during transit. Care should be taken that loading is halted during rain, and that holds are closed when the entrance of water is possible. Exclusion of water is essential to ensure that the timber reach its destination in clean, sound condition. It goes without saying that the shipping of lumber as a deck-load is a practice greatly to be condemned, since the exposure to which the wood is subjected may lead to serious deterioration.

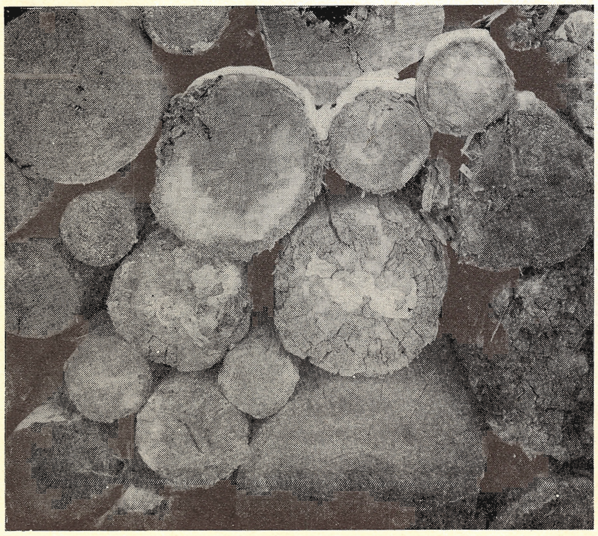


Plate 58.—Decaying Pulpwood in Storage Yard.

Relative Durability

Sapwood and Heartwood

No species of wood produces a durable sapwood. The structural and chemical properties which render the timber of some tree species very resistant to decay are developed only when heartwood is formed. In the sapwood of nineteen species tested by Humphrey (10) practically no difference in durability was noted; all were very non-resistant. Hubert (9) tested the relative durability of the heartwood and sapwood of western red cedar, one of the most resistant native species. He found that the sapwood rotted rapidly. Tests of the toxicity of extractives made from the wood showed that the resistance of the heartwood of this species is due to the presence of toxic substances; a 50 per cent concentration of the extractive inhibited growth of the fungus tested, and a 100 per cent concentration killed it. Sapwood extractives, on the other hand, were favourable to the growth of the fungus.

Heartwood of Different Species

Laboratory tests of the resistance of different species of wood to different fungi under controlled conditions provide some information regarding the durability of various species of wood, but the unlimited number of combinations of environmental factors which might be tested renders the problem so complex that comparatively few informative experiments have been carried out. Results of some tests have been somewhat contradictory, and some have even led to conclusions at variance with common experience in the use of different species. Thus Schmitz

(17), in a comparative study of seven western softwoods found white fir, *Abies grandis* (Dougl.) Lindl., which is usually considered very susceptible to disease, second only to white cedar in decay-resistance. Efforts are being made to establish standard tests, which will provide a basis for more accurate information.

Knowledge of the relative durability of different species of wood is based for the most part on records of the life of railway ties, telegraph poles, bridge timbers, etc. kept by engineers. Since it is impossible to analyse the environmental conditions under which such timbers are placed, and since the complexity of the life processes of fungi make even apparently minor changes in the environment of possible significance in their development, such records do not form a basis for specific recommendations regarding the use of different kinds of wood: they are not sufficiently definite to enable us to foretell accurately the service life of any species when placed in particular situations. They are, however, indicative of the service life which may be expected from different species. Variations in temperature and humidity of soil and air, in texture and composition of soil, in precipitation, and in other factors influence the development of wood-rotting fungi. In addition, wood in some situations may remain sound for some time owing to the absence of virulent wood-destroyers from the location in which it is placed in service, although, owing to the ubiquitous distribution of wood-destroying fungi, such a condition could exist but temporarily, and would prolong the life of the timber for but a limited period.

Service records, coupled with general experience in the use of wood, have supplied a basis for the separation of the commercial woods into groups of durable and non-durable species. A useful list compiled from such information has been published by the United States Forest Products Laboratory, Madison, Wis. (11). For practical purposes, such a classification is usually sufficient. In conditions favouring decay, no wood is absolutely immune from attack. Therefore, in situations in which decay of timber will entail unduly extensive replacements in a permanent structure, untreated wood should not be used where the development of fungi is likely. In positions in which fungi cannot develop, no species will decay. Choice of wood for such situations is, therefore, based on qualities other than durability.

Common Types of Decay

Rots are often classified as white rots or brown rots, according to the colour displayed by advanced stages of the diseased wood. The white rots correspond broadly to the "corrosive" type of Falck (2) in which the fungus first attacks the lignin complex. Even in the final stages of some white rots the cellulose remains intact. Thus, spruce containing advanced *Fomes pini* rot is found to give a yield of chemical pulp equivalent in amount to that produced by the same volume of sound wood. In other white rots, however, decomposition of cellulose succeeds or accompanies that of lignin, and the decayed wood decreases in value as a source of pulp production. In the brown rots, decay of the "destructive" type (2) occurs; cellulose is assimilated by the invading fungus, and lignin is left. In this type, the decaying wood becomes brown in colour and gradually decomposes until it can be readily broken and powdered between the fingers.

Wood-rotting fungi show specific differences in the type of wood which they attack. Of the species discussed below, *Fomes fomentarius* infects the sapwood of living hardwoods, thereby gradually causing the death of the trees attacked, and may eventually bring about decay of the entire heartwood. *Lenzites saepiaria* attacks for the most part dead softwoods, infecting either heartwood or sapwood; it may cause the complete destruction of both. A few fungi are limited in their range by their dependence upon a certain host; others develop on a certain class of hosts. Of the latter may be mentioned *Fomes pini*, which has been found to be confined to conifers.

Timber cut from standing trees frequently contains rot, and much of this infected wood can be used in situations where maximum strength is not required. Current opinion holds that as a rule rots initiated in the standing tree do not continue under conditions of service. This is doubtless true of many types of decay, but some fungi are known to remain active in felled timber, and with regard to others incomplete records leave us in doubt as to their reactions to such changes of environment.

Of the many fungi which attack our Canadian timbers, space permits mention of but a few. Those discussed below are chosen because of their widespread occurrence or great virulence.

Rots prevalent in standing hardwoods are caused by *Fomes fomentarius* and *Fomes igniarius*.

PLATE 59.—*Lentinus lepideus* Fr. Fruiting on Decaying Pile Foundation in a Lumber-seasoning Yard.

Of the many fungi which attack standing softwoods, two have been selected for comment: *Fomes pini* and *Stereum sanguinolentum.* These fungi are prevalent in pulpwood, and are a cause of serious economic loss.

Fomes fomentarius (L.) Gill.

This fungus is very common in birch, beech, maple, and poplar, in which it causes decay of both heartwood and sapwood. Rot begins in the sapwood, but may eventually affect the entire trunk. The wood becomes yellowish in colour, soft, and light; and in checks opened up by shrinkage of the wood, sheets of the buff-coloured mycelium may be found (Plate 61).

The fungus produces an abundance of hard, greyish, hoof-shaped fruit-bodies (Plate 62). On the lower surface—that is, the surface facing the ground—which is greyish-buff in colour, there are comparatively large, regular pores. These are the mouths of vertical tubes, in which the spores are produced (Plate 63). The fruit-bodies are perennial, new tubes being formed annually over a period of several successive years.

Fomes igniarius (L.) Gill

This fungus causes the common white rot (Plate 64), which occurs in greater or lesser abundance in all hardwood species throughout Canada. Infection enters through wounds, and decay is first set up in the heartwood. As the rot advances, the wood becomes whitish in colour and soft. In cross-section, the rotted area presents an irregular outline with narrow black lines, and a brownish zone bordering the region of advanced decay. The rot finally spreads to the sapwood and completes the destruction of the tree; it may extend throughout the length of the trunk.

Fruit-bodies of the fungus develop on the exterior of trees or fallen logs. They are perennial, shelf- or hoof-shaped, and hard, with upper surface greyish to black, ridged, and cracked. The lower surface, in which may be noted the very fine circular mouths of the spore tubes, is rusty-brown in colour.

Fomes pini Karst

Fomes pini (formerly *Trametes Pini*) is the most prevalent and virulent of the fungi which infect standing softwoods. It has been reported from practically all the coniferous species. In early stages of the disease, the wood becomes pink, reddish, or reddish-purple, but remains apparently firm; as decay proceeds, white pockets appear in the stained areas, and the disintegration of the wood becomes evident to the unaided eye (Plate 65). The rot may involve the entire heartwood, and in extreme cases may even embrace the sapwood, but frequently it is confined to a few annual rings, and a cross-section of the trunk will then reveal circular or crescent-shaped patches of decay. In the latter case, the destruction of a few annual rings leads to ring-shake, a common type of defect caused by this fungus. Decay may extend throughout the entire trunk, or be limited to the vicinity of points where the fungus entered the tree.

PLATE 60.—*Polyporus versicolor* (L.) Fr. Fruiting on Decaying Log used in Pile Foundation in Lumber-seasoning Yard.

Under favourable conditions, fruit-bodies (Plate 66) form on the outside of the tree, when rot is sufficiently advanced. They are perennial, shelving to hoof-shaped, with a woolly, brown upper surface, on which concentric zones may be noted. With age the colour darkens and the surface may become smooth. The fruit-bodies vary in size, but may reach a width of six or seven inches, and project two to seven inches. The lower surface, when young and fresh, is orange-brown to brown in colour, and contains pores, somewhat irregular in shape, which are the mouths of vertical spore-tubes.

Whether or not the rot caused by *Fomes pini* continues to develop under service conditions is a question which has caused much anxiety to certain purchasers of infected material. The disease is prevalent in standing jack pine, from which, among other things, poles and railway ties are manufactured. The advisability of accepting for service timbers containing "red stain" has always been a question with users of jack pine. Mechanical tests have shown that red-stained jack pine does not differ appreciably in strength from clear material, but that once the pocket stage of the disease is reached, serious reduction of strength occurs (12, 15). In 1929, 396 selected, red-stained ties were installed in track in connection with a study by the Laboratory of this question. The ties were manufactured in 1926, tested for the presence of red-staining fungi, and seasoned. Half of the ties were then creosoted, and the treated and untreated ties placed in a main-line track. At

PLATE 62.—Fruit-body of *Fomes fomentarius* (L.) Gill.

PLATE 63.—Vertical Section of Fruit-body Shown Above.

PLATE 61.—Rot in Birch Caused by *Fomes fomentarius* (L.) Gill.

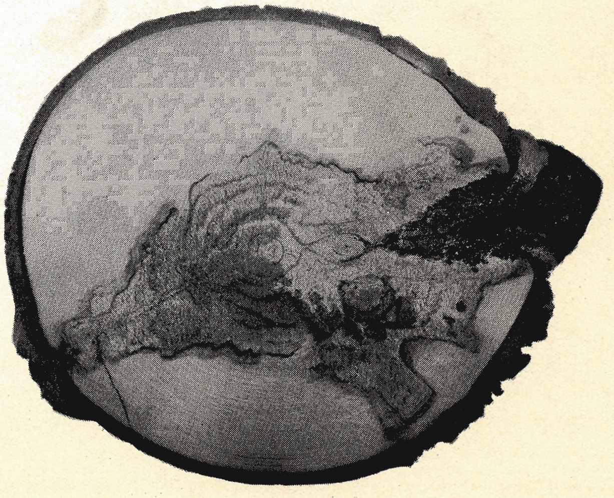


PLATE 64.—White Rot in Poplar Caused by *Fomes igniarius* (L.) Gill, with Fruit-body of the Fungus Attached.

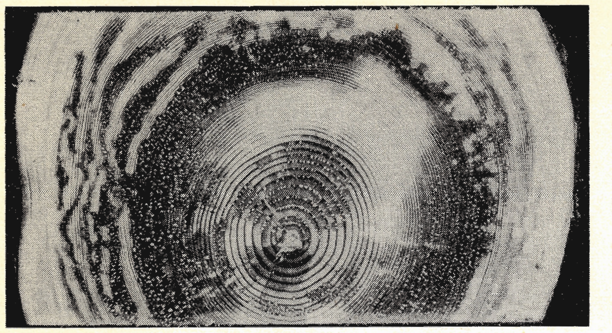


PLATE 65.—Red Rot in Jack Pine Caused by *Fomes pini* Karst.

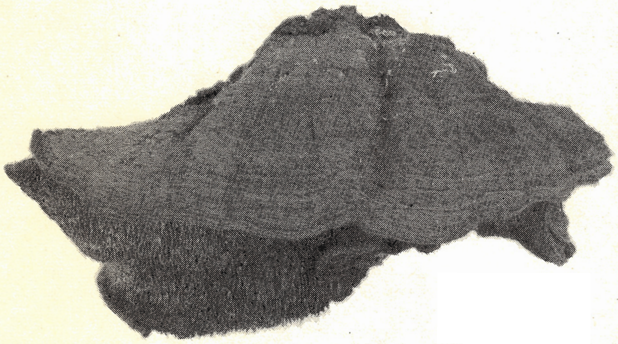


PLATE 66.—Fruit-body of *Fomes pini* Karst.

PLATE 67.—Red Heart in Balsam Fir Caused by *Stereum sanguinolentum* Alb. & Schw.

one- to two-year intervals since the track was established groups of ties have been removed and analysed. The untreated ties had all been removed at the end of ten years, and all of the treated ties by the summer of 1950. *Fomes pini* has been found alive in one or more ties in each group of removals; in 1950 (over twenty-four years after the trees were felled) the fungus was isolated from several points in one tie. Careful study of the ties, however, has shown that *Fomes pini*, although possibly alive, does not cause deterioration of the wood in track. Red-stained jack pine can, therefore, be accepted with the assurance that its service life will not be affected by the presence of *Fomes pini* infection.

***Stereum sanguinolentum* Alb. & Schw.**

The rot caused by *Stereum sanguinolentum* is abundant in balsam fir, and not infrequent in spruce. It is responsible for much cull in pulpwood in the forest; and, since it has often been found fruiting in block piles, it is obvious that its growth continues during storage.

Infection enters the standing tree through branch stubs, and the heartwood is destroyed. Decay is often confined to the top logs, but it may extend throughout the trunk. The wood becomes reddish-brown in colour, and attains a very high moisture content. Rot may involve the entire heartwood, forming a complete cylinder of decay, or it may occur as scattered, irregular streaks. Seen in cross-section (Plate 67) the rot is often found to have an irregular, deeply indented margin, which gives a very characteristic appearance to the infected wood. As decay proceeds, white mycelial sheets form in the wood. In very advanced stages, the wood becomes dry, and so thoroughly disintegrated that it is readily powdered between the fingers.

The fruit-bodies (Plate 68) are thin, spreading as sheets over the surface of the wood, or with the upper portion rolled free and forming a thin, narrow, elongated shelf. They are greyish or greyish-buff in colour, and smooth. The spores develop on the smooth, exposed surface and not in tubes; hence no pores, as in species discussed above, are to be noted. When wounded, a fresh fruit-body will exude a blood-red juice, characteristic of the species.

Tests of the pulping value of infected wood showed that yields, either by weight or volume, were not materially lower than those from sound wood,

except in cases of very advanced decay in which the wood was noticeably soft or friable (16).

Fomes pinicola (Sw.) Cooke

One of the most widespread types of decay is caused by *Fomes pinicola.* The fruit-bodies are abundant, and may be found on both hardwoods and softwoods.

This fungus causes a very common brown rot in the sapwood and heartwood of softwoods and hardwoods. It is found in standing trees, but is more common in felled timber. In early stages of decay, the wood becomes soft and yellowish in colour. As decay proceeds, the wood shrinks and cracks, and a typical reddish-brown cuboidal rot, in the cracks of which soft white mycelial felts are formed, is produced (Plate 69).

The fungus fruits abundantly, producing large perennial conchs. These are hoof-shaped or shelving, with upper surface black to brown in colour, but with a thick, shiny, reddish or yellowish margin. The lower surface is creamy white to yellowish, and contains the tiny, regular mouths of the spore-tubes.

Fungi Affecting Felled Timber and Lumber

Of the fungi active in the destruction of exposed wood in storage and service, four have been selected as of especial economic importance; namely, *Lenzites saepiaria*, *Lenzites trabea*, *Fomes roseus*, and *Lentinus lepideus*.

Of the building-rot fungi, *Merulius lachrymans* has perhaps been more extensively studied than any other species. It occurs fairly frequently in Canada; and its great virulence when once established, as well as the peculiarities of its development, justify a brief discussion of the decay it produces.

Lenzites saepiaria Fr.

This fungus is probably the most active destroyer of softwoods both in storage and in service, throughout Canada. It attacks fallen logs in the forest, stored logs and lumber, untreated railway ties, fence-posts, telegraph poles, and all exposed timber, and is active in damp situations in buildings. In collections made on several pulpwood block piles, its fruit-bodies were more abundant and conspicuous than those of any other fungus. It has been reported on living trees, and is occasionally found attacking hardwood, but its activity in such situations is of minor importance.

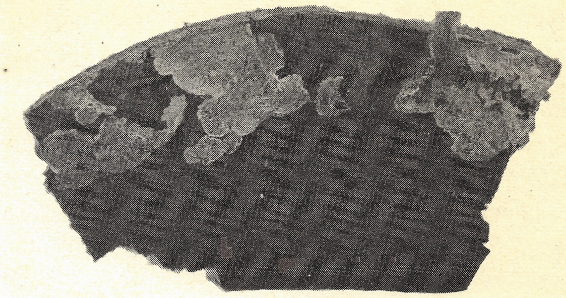


PLATE 68.—Fruit-body of *Stereum sanguinolentum* Alb. & Schw.

PLATE 69.—Red Rot of Spruce Caused by *Fomes pinicola* (Sw.) Cooke, with Fruit-body of the Fungus Attached.

PLATE 70.—Brown Rot in Jack Pine Caused by *Lenzites saepiaria* Fr.

The rot caused by *Lenzites saepiaria* is of the brown cuboidal type (Plate 71). Decay usually begins in the sapwood, the fungus frequently entering through seasoning checks. In early stages, the wood becomes yellowish and soft, and may in some cases present a somewhat laminated appearance owing to rapid attack of the fungus on the spring-wood. The rot often occurs in pockets, which merge as decay proceeds. The wood shrinks and checks radially and tangentially, and mycelial strands or irregular sheets extend through the decayed tissues. In the final stages, heartwood as well as sapwood may be completely reduced to a yellowish-brown friable mass.

The young fruit-bodies are yellowish or orange-yellow, with hairy to woolly zonated upper surface; as they age, the colour changes to rusty or dark brown. They are perennial, and old fruit-bodies, on which a new spore surface and fresh marginal growth have developed, are abundant. The fruit-bodies are comparatively small, and somewhat leathery in texture (Plate 71). On vertical, lateral surfaces, they form narrow elongated shelves, which may project as much as two inches; on end surfaces, numerous small, shelving fruit-bodies may develop; on horizontal surfaces facing the ground, the fruit-bodies remain appressed to the substratum, while on upper surfaces they may be somewhat stalked or may appear as bilateral shelves. Under unfavourable conditions, particularly in dark situations, stalked and twisted abortive fruit-bodies are often found. The lower surface is formed of branched, anastomosing vertical plates or gills, which when fresh are yellowish in colour; occasionally fruit-bodies, the lower surfaces of which display more or less regular pores, are found. The spores develop on the gills, or in the tubes of which the pores are the mouths.

Lenzites trabea Pers.

This fungus is an active destroyer of dead wood of both softwood and hardwood species. It attacks felled logs, stored logs, and lumber; it is active in pulpwood block piles, destroys exposed wood in service; and is prevalent as an agent in the destruction of building timbers. The rot is similar in appearance to that caused by *Lenzites saepiaria*. That these two fungi may unite in attack on the same piece of wood is evidenced by the fact that mycelium of both developed in culture from a fragment of rotted wood removed from a decayed block of jack pine.

Plate 71.—Fruit-body of *Lenzites saepiaria* Fr.

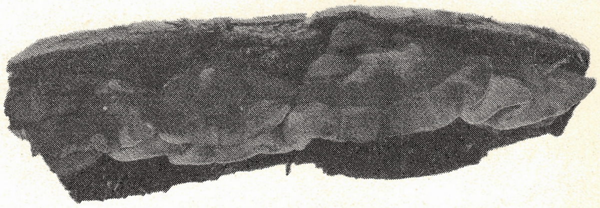


Plate 72.—Fruit-body of *Lenzites trabea* Pers.

Plate 73.—Brown Rot in Spruce Caused by *Fomes roseus* (Alb. & Schw.) Cooke, with Fruit-body of Fungus Attached.

The fruit-body of *Lenzites trabea* (Plate 72) is greyish to reddish-brown in colour, and develops as a narrow elongated shelf, or may remain for the most part appressed to the surface of attachment, sometimes with the upper edge reflexed to form a narrow shelf. The lower surface, from which the spores are shed, contains irregular pores, vertical anastomosing plates, or, rarely, gills.

Fomes roseus (Alb. & Schw.) Cooke

Fomes roseus destroys the heartwood of living softwoods, is sometimes found on living birch and maple, and is widespread as a destroyer of exposed wood and building timbers. The rot produced is of the brown cuboidal type. It usually begins in elongated pockets, which finally merge, so that the rot embraces the entire heartwood. The decayed wood varies in colour from light to dark brown, and in the cracks formed by shrinkage thin sheets of whitish or rose-coloured mycelium may develop.

The fruit-bodies are shelving or hoof-shaped, soft to woody in texture, smooth, pinkish-brown to black above, and with a lower surface pinkish to rose in colour and containing tiny pores (Plate 73); the inner tissue of the fruit-body is also rose-tinted. The fruit-bodies grow up to four inches in width and may project as much as three inches; they are often found overlapping or merging to form compound bodies. Annual and perennial forms of the fruit-body are found.

Lentinus lepideus Fr.

Lentinus lepideus has been reported as responsible for the production of a heartwood rot of living pines, but is more generally known as a cause of decay of softwoods in storage or service. It may also attack hardwoods. It is an active destroyer of exposed wood and a common cause of decay in building timbers. The rot produced by this fungus is of the cuboidal type. In an early stage, the wood becomes yellowish and soft; as decay proceeds, it turns dark reddish-brown, and becomes gradually more or less fragmented by the development of shrinkage cracks, which may become filled with sheets of mycelium.

The fruit-bodies are of the mushroom type (Plate 59), fleshy, with central or lateral stem bearing a circular cap, on the under side of which are numerous radially arranged plates or gills, which are oriented in a vertical plane. The spores are shed from the surfaces of the gills. The cap is whitish, with brownish scales; the gills whitish, with irregularly toothed margins; and the stem whitish, with a downy or scaly surface.

Merulius lachrymans (Jacq.) Fr.

Merulius lachrymans is known as a true "dry-rot" fungus; but it must be remembered that it can begin growth only in damp wood. Once established, this disease can be eradicated only by the most considered and persistent effort. The fungus grows profusely in damp cellars and mines, penetrating wood structures, and producing on exposed surfaces snowy white mycelial mats, from which glistening moisture drops usually exude. Under certain conditions, these surface mats become tinged with yellow or lilac; in drier situations they may be replaced by thin greyish mycelial sheets. From centres of profuse growth, the fungus sends out mycelial strands which may pass over brick-work, plaster, or other material and carry infection to wood-work far distant from structures originally infected. These strands conduct water, and thus enable the fungus to infect wood of low moisture content. It is also stated that in the decomposition carried on by this fungus water is produced; this acts as an additional aid in the spread of the disease.

The rot produced is of the brown, cuboidal type, and in advanced stages the wood is crumbly and easily powdered between the fingers. Thick, soft mycelial sheets develop in the shrinkage cracks.

The fruit-bodies develop over the surface of attachment as soft, fleshy sheets, or spread out as thin, soft, shelving structures (Plate 74). As the fruit-bodies mature, ridges divide the surface into shallow pits, on the walls of which rusty-red spores develop in profusion.

The first step in the eradication of this fungus is elimination of the source of moisture which has permitted it to become established in the building. Consideration must then be given to the power of the

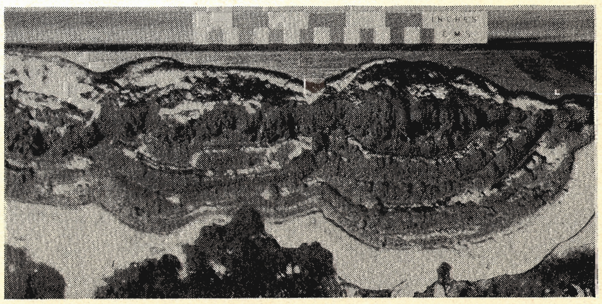


PLATE 74.—Fruit-body of *Merulius lachrymans* (Jacq.) Fr.

fungus to spread far from the timbers originally infected. Strands must be traced to the limit of their growth; all infected wood must be removed; and all surfaces over which the fungus has grown must be disinfected with a suitable wood preservative (see Chapter 7).

STAINS

Stains in lumber are due to one of two causes—chemical changes in the wood accompanied by local deposition of coloured substances, or development of fungi in the wood. Discolorations occur in both heartwood and sapwood; those which affect sapwood are of greater economic importance, but most discolorations lower the grade of the product in which they occur. Following are some of the more common stains which have been noted.

Heartwood Stains

Chemical Brown Stain. This develops, particularly in white pine, during yard-seasoning or kiln-drying. It appears as brownish patches or streaks, chiefly in the heartwood but occasionally in the inner sapwood. The nature of the stain and seasoning methods which tend to prevent its development are dealt with in Chapter 5.

Mineral Stain. This defect occurs in maple and ash heartwood as greenish to greyish, lenticular patches or streaks. The wood in the discolored areas is harder than clear material, and this causes trouble in seasoning and machining. The cause of the stain is not known. It has been attributed to deposition of chemicals from the soil in the living tree; but the presence of fungal threads suggests that it may be an early stage of heartwood rot.

Fungal Stains. The early stage of heartwood rots is characterized by discoloration of the wood. Yellow-brown, reddish-brown, red, or purplish tones appear as a wood-rot fungus invades the wood; dark reddish, brownish, or greyish bands bordering more advanced decay are also found.

Some discolorations in heartwood are produced by staining fungi which are not known to cause rot in their final stages of activity. Of these discolorations, red-heart in birch, red stain in Manitoba maple (box elder), greyish-black stain in ash, two distinct red discolorations in jack pine, and streaks of different colours in other species, have been associated with definite fungi. These stains originate in the standing tree, while the sapwood staining species develop in felled timber.

Sapwood Stains

Sapwood stains develop as a result of the growth of a variety of fungi growing singly or in association in infected logs or lumber. Bluish or greyish discolorations are most frequent, but brown, yellow, pinkish, reddish, and purplish discolorations also occur. The stains may be due to coloured mycelium or to infiltration into the cell walls of the wood of substances produced by the invading fungi during their growth processes. The fungi may produce merely a superficial stain, which is removed when the lumber is dressed, or they may penetrate and discolor the entire sapwood.

None of the staining fungi give rise to conspicuous fruit-bodies, such as those borne by wood-rotting species. Some produce myriads of tiny, black, flask-shaped fruit-bodies from which spores are shed, and all bear spores on surface growths of mycelium, which is not organized into definite forms of fructification. Stain spreads in the same manner as decay, namely, by the dispersal and germination of spores, or by contact of sound with infected material.

Conditions Favouring or Inhibiting Development

Sapwood-staining fungi develop under conditions very similar to those which favour the growth of wood-destroyers. They develop best in warm, humid situations, but growth is not inhibited until the temperature drops to the vicinity of freezing. Living, healthy sapwood is immune from stain, because the moisture content is too high for its development, but a reduction of 10 per cent permits entrance of the fungi, and the wood remains susceptible to attack until it has dropped below the fibre-saturation point.

What has been said regarding the control of wood-destroying fungi applies equally to those which cause stain. In infected material, they are not necessarily killed by drying, but their growth is inhibited. A rise in moisture content will permit them to revive and continue development, but saturation again halts their growth, and, if continued, kills the fungi. With regard to temperature, freezing does not kill staining fungi, but it renders them inactive. They do not, however, tolerate prolonged subjection to high temperatures; tests made of stained sticks 4 inches by 4 inches by 24 inches in size showed (7)

that the fungi tested were killed by subjection to temperatures obtaining in ordinary kiln-drying schedules (see Chapter 5).

Effect on Wood

Sap-staining fungi differ from those which cause decay of wood in that they feed upon the food reserves stored in the ray and wood-parenchyma cells (see Chapter 3), and not upon the cell-wall substance. In the case of staining, therefore, the fungal hyphae are more or less concentrated in the cells; and, although penetration of the cell walls does occur, no apparent disintegration of the wood takes place.

It has been rather generally accepted that stained wood is equal in mechanical strength to unstained wood of similar quality. Within recent years, however, it has been shown that variations depending on the strength property under consideration, the fungus producing the stain, and the species of wood attacked, do occur. Controlled tests on Scots pine sapwood (3) revealed a reduction in toughness up to 30 percent in unsteamed wood infected with *Ceratostomella coerulea*; they indicated also that the modulus of elasticity was adversely affected although not sufficiently to be of practical significance (4). In tests on Corsican pine infected with *Ceratostomella coerulea*, *C. pilifera*, and *Diplodia natalensis* it was found that the effect of *Diplodia* on tensile strength was much more marked than that of either species of *Ceratostomella* (14). A study of Obeche infected with *Botryodiplodia theobromae* showed a reduction in toughness up to 43 per cent, accompanied by reduction in bending strength, stiffness, and specific gravity (5). In addition to possible reduction in strength, the fact that wood is stained indicates that it has been subjected to conditions favourable to the growth of fungi. Since staining and wood-destroying fungi develop under similar conditions, the occurrence of stain immediately casts suspicion upon the quality of the wood; incipient decay may be present, masked by the deeper discoloration caused by the staining fungi. In all cases where maximum strength is required, therefore, stained wood should be rejected.

The greatest loss due to staining is occasioned by the unsightly discolorations which develop (Plate 75), and render the wood unfit for uses in which appearance is a factor of importance. According to the species of wood infected, and the fungus producing the stain, the discolorations may range through a great variety of colours.

PLATE 75.—Blue stain in Sapwood of Eastern White Pine.

Distribution

Standing trees are attacked by sapwood-staining fungi only when weakened by root injury, drought, fire, or other factor causing a decrease of water in sapwood. Logs stored in the woods, or otherwise exposed to slow drying or to alternate wetting and drying, may stain with great rapidity under temperature conditions favourable to fungal growth. Lumber stacked green from the saw in the seasoning yards is very susceptible to stain under warm, humid conditions.

Certain species of wood are extremely susceptible to stain. Of Canadian timbers, certain of the pines are most readily infected, but many species of both hardwoods and softwoods stain if held under conditions favourable to growth of fungi.

Control

If lumber is kiln-dried as it comes from the saw and then kept dry, all possibility of the development of sapwood stain is eliminated. In lumber to be air-seasoned, however, special precautions must be taken. The aim at each mill should be the exclusion of all sources of fungal infection from the yards; all diseased wood present as construction timbers or waste should be cleared away before clean lumber reaches the piles. Conditions depicted in Plates 57 to 60 should not exist. Attention should also be directed to logs arriving at the mill. Stained logs and lumber made from them should be segregated; they should not be allowed to contaminate clean material. Since rapid removal of moisture from the lumber reduces susceptibility to stain, careful attention should be given to yard arrangements and correct methods of piling; a discussion of these topics will be found in Chapter 5.

Owing to the ubiquitous nature of sapwood-staining fungi, and the comparatively long period necessary to reduce the moisture content of wood to a point at which infection is inhibited, stain may develop even in yards where methods of sanitation and piling are of a high order. It is, therefore, advisable, as lumber of susceptible species leaves the saw, to treat the rough boards with some chemical that is toxic to staining fungi. All sapwood boards should be completely immersed or thoroughly sprayed on all surfaces with a solution of the chemical selected.

Extensive tests have been carried out in Europe and America in an endeavour to find chemicals to control stain in both hardwood and softwood lumber. Several highly effective proprietary compounds are now on the market and are widely used in the lumber industry. These contain chlorinated phenols or organic mercurials, singly or in combination, as the chief toxic ingredients. It must be remembered that, for effective control, treatment must be applied immediately the boards are manufactured. If staining fungi are permitted to become established in the lumber, surface treatment will be quite ineffective in preventing their continued development.

Indian Chief's Grave, Musquiam, B.C.

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Refrigerator for the Storage of Cultures.

The characteristics of wood-inhabiting fungi in culture are sufficiently constant to serve as aids in identification. Standard cultures are developed from spores or sporophore tissue; cultures made from decayed wood are identified by comparison with the standard set. The standard collection at the Ottawa Laboratory contains upwards of 700 isolates, representing some 200 species.

PRESERVATIVE TREATMENT OF WOOD

by J. F. HARKOM

REASONS FOR TREATMENT

IN CANADA, wood has generally been the cheapest and most suitable material available for house construction and other purposes. Unfortunately, the reputation of wood as a construction material suffers from the manner in which it has often been used in the past. Only too frequently, wooden houses have been built in circumstances where the money available was barely sufficient to provide for the erection of a weatherproof dwelling, and no funds were available to improve the general appearance of the structure or to provide any degree of protection for the wood. Consequently, throughout the countryside may be found wooden buildings in various stages of dilapidation, and a totally erroneous impression is induced as to the inevitability of the deterioration of timber buildings in service. The possibilities of obtaining improved appearance by means of better designs and of ensuring permanency through preservative treatments are overlooked. On the other hand, steel structures (such as bridges) are usually erected by those who realize that this material must be protected from the elements, and who have the necessary funds to invest in protective coatings. The rusting of steel is an inorganic process, caused by the oxygen in the air combining with the metal to form iron oxide or rust. It is thus a surface action and may be effectively prevented by covering the surface with paint. The decay of wood is an organic process, which takes place both at and beneath the surface, and protective measures must extend below the surface in order to be effective. The art of wood preservation consists in obtaining the required surface and sub-surface protection at the lowest possible cost.

The chief causes of the deterioration or destruction of timber in service are decay, insects, marine borers, weathering, and fire.

Decay

The decay of wood, which is discussed fully in Chapter 6, is caused by the growth in the wood of low forms of plant life known as fungi. In order to protect timber from decay, it may be impregnated with chemicals to poison the wood substance, which is the food on which the fungi grow. Decay is by far the most important factor in the deterioration of timber in service in Canada.

Insects

Very fortunately, timber in service in Canada is comparatively free from destruction by insects. Unpeeled logs left on the ground in the bush are exposed to damage by the action of insects, but attacks on fence-posts, poles, or structural timbers are so infrequent that there is little or no demand in Canada for lumber treated to resist insect attack. In other countries, where termites are prevalent, it is necessary to provide adequate measures of protection. Fortunately, the chemicals used to protect timber from decay will usually provide protection from insect attack.

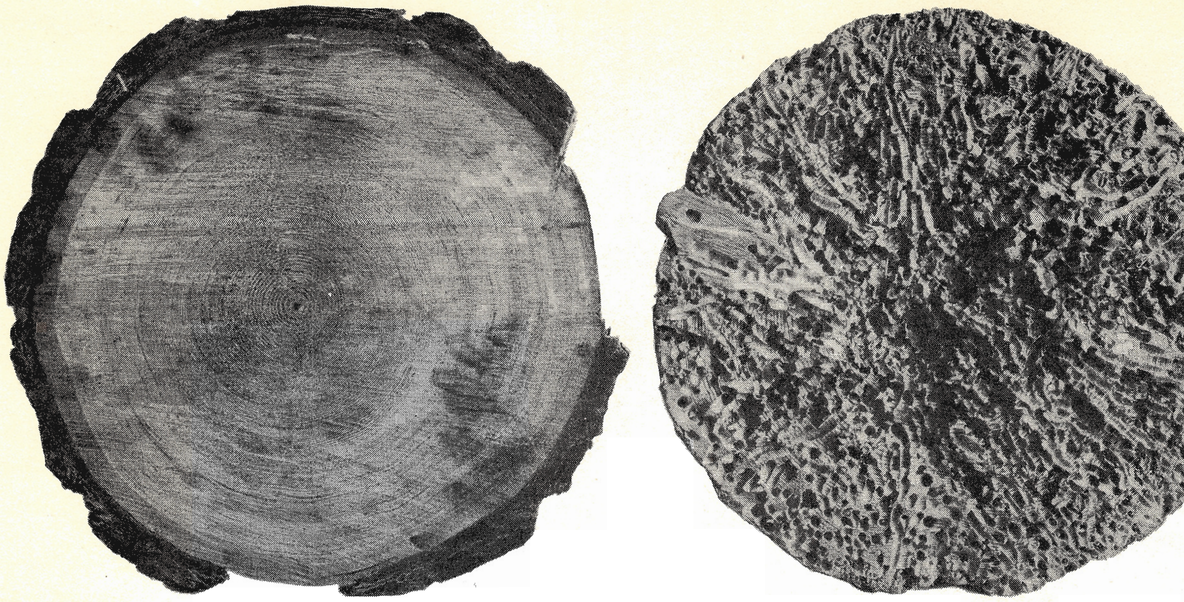


PLATE 76.—Section of Douglas Fir Pile Before and Following a Month's Exposure to Teredo. Burrard Inlet, B.C.

Marine Borers

Wood submerged in fresh water will last indefinitely, but sea water in many parts of the world, including the Atlantic and Pacific Coasts of Canada, is infested with marine borers which burrow in the wood for shelter and food and eventually totally destroy it. Marine borers may be divided into two classes, the *molluscs*, commonly known as *teredo* or *shipworms*, and the *crustaceans*, which are known as *limnoria* or *wood lice*.

Teredo attack starts when a small floating embryo attaches itself to the wood and bores a minute hole. When once the teredo penetrates beneath the surface, the hole is extended and enlarged to accommodate the rapidly growing body, and eventually the timber is honeycombed with longitudinal galleries or burrows, usually 6 inches to 12 inches in length and one-quarter of an inch in diameter. Plate 76 shows the appearance of the interior of a pile attacked by the teredo. The original entrance hole is not enlarged, so that what is in appearance a sound pile may be nothing but a weakened, honeycombed shell.

The attack of the limnoria is quite different from that of the teredo, inasmuch as the timber is eaten away on the surface and the damage is apparent to the eye. Limnoria are about the size of a grain of rice, and excavate little galleries, side by side, extending about half an inch below the surface. These galleries are so numerous and so close together that the partitions of wood between the tunnels are soon broken away by the action of the waves. The limnoria then make fresh galleries, which in turn disintegrate. The piling attacked is consequently eaten away until it resembles an hour-glass, as shown in Plate 77.

The attack of marine borers can be effectively prevented by treating the timber with creosote.

Weathering

When unpainted wood is exposed to the weather, the moisture content of the outer fibres fluctuates with changes in atmospheric conditions. The repeated swelling and shrinking caused by the

PLATE 77.—Piling Attacked by Limnoria.

change in moisture content gradually loosens the outer fibres, and the wood acquires the well-known weathered appearance. Weathering can be prevented by paints specially prepared for use on exterior woodwork.

Fire-retardant Treatments

The three chief factors to consider in the protection of construction material from fire are:

(1) *Ease of ignition or inflammability.*

(2) *Resistance to change of shape or loss of strength on heating.*

(3) *Rate of intensity of burning, which is largely a question of the conditions of air supply.*

If due consideration is given to all three factors, wood compares quite favourably with other construction materials.

Wood can be impregnated with certain chemicals which render it comparatively resistant to fire; that is to say, if a piece of wood so treated is placed in a fire, it will merely char or disintegrate slowly, instead of burning briskly, and if it is removed from the fire, or the surrounding fire dies out, it will not continue to burn. Such treatments, however, are expensive, and it is often difficult to justify the expense of using fire-retardant treated wood, as is indicated by the slow adoption of this type of building material.

The most effective fire-retardant chemical is ammonium phosphate, which will prevent afterglow as well as flaming. Other chemicals, such as ammonium sulphate, borax, and boric acid are nearly as effective as ammonium phosphate in preventing flaming, but do not check the after-glow to the same extent. Since ammonium phosphate, either dibasic or monobasic, is so effective in preventing afterglow, it is often mixed with other fire-retardant chemicals which are cheaper but do not have this desirable property.

Below are listed chemicals and combinations of chemicals for pressure fire-retardant treatment of wood which have been considered and submitted for information by Committee 9—Fireproofing, of the American Wood-Preservers' Association.

For fire-retardant treatment, the quantity of chemical used is very important, and should vary with the thickness of the timber in accordance with the ratio of surface area to volume.

For a high degree of fire resistance, the following absorptions are required, and wood so treated will neither spread flame nor contribute to its own combustion.

2″ and under . 6 lbs. per cubic foot of wood.
2″ to 4″ . . . . . 5 lbs. per cubic foot of wood.
4″ to 6″ . . . . . 4.5 lbs. per cubic foot of wood.
6″ to 8″ . . . . . 4 lbs. per cubic foot of wood.

The equipment required for the pressure treatment of wood with fire-retardant chemicals is similar to that used for treatments to prevent decay. Additional facilities for kiln-drying the wood after treatment are usually required. At the present time, the pressure-treating plants in Canada are not equipped with dry-kilns, so that it is difficult to purchase in Canada wood treated with fire-retardants.

CHEMICALS

TYPE	COMPOUND	FORMULA	APPROXIMATE PROPORTION OF CHEMICALS
1	Sodium dichromate	$Na_2Cr_2O_7$	3 (min.)
	Ammonium sulphate	$(NH_4)_2SO_4$	78
	Ammonium phosphate (monobasic)	$(NH_4)H_2PO_4$	19 (min. 15)
2	Ammonium phosphate (dibasic)	$(NH_4)_2HPO_4$	10 (min. 9)
	Ammonium sulphate	$(NH_4)_2SO_4$	60 (min. 54)
	Sodium tetraborate (borax)	$Na_2B_4O_7$	10 ± 2
	Boric acid	H_3BO_3	20 ± 4
3	Sodium tetraborate (borax)	$Na_2B_4O_7$	60 ± 10
	Boric acid	H_3BO_3	40 ± 10
4	Zinc chloride	$ZnCl_2$	....
	Chromated zinc chloride	....	....
5	Proprietary formulas	....	....

Fire-retardant Paints

The ignition of wood may be retarded by the use of fire-retardant paint. All that can be claimed for such a paint is that a surface coating can be used which will hinder the spread of flame and prevent the ignition of timber from a small fire. If the coating is subjected to intense heat from the combustion of adjacent material, naturally no very great degree of retardation can be expected. What a good fire-retardant paint can do is to prevent small fires from becoming large ones.

DEVELOPMENT OF THE WOOD-PRESERVATION INDUSTRY

THE modern wood-preservation industry may be said to have started with experiments carried out in the late eighteenth and early nineteenth century in England to protect wooden warships from decay. Shortly afterwards, the development of railways created a demand for durable wooden ties; treating plants were gradually established throughout Europe, and during their initial years of operation these plants depended largely on the railways for revenue. As the advantages of treatment became more widely known, mine timbers, telephone and telegraph poles, cross-arms, marine piling, fence-posts, and, generally, wood intended for use in conditions favouring decay, have been treated in increasing quantities. During recent years, bridge and structural timbers have formed a larger percentage of the total material treated.

Decay may be prevented by keeping timber dry and away from contact with the soil, as well as by preservative treatment. The tendency in the design of structures incorporating untreated wood has been to use expensive stone or concrete foundations in many locations where treated wood might be much more economical.

The further development of the wood-preservation industry depends largely on educating consumers with regard to the manner in which the use of treated wood permits the development of more economical designs, which, when followed, more than pay for the cost of treatment. If this is done, a demand will be created, and it will be economically feasible to stock treated wood at retail lumber yards. To attempt to distribute treated wood by simply setting up yard stocks is not sufficient; the treated wood might be available, but consumers would not know how to use it to best advantage. What is required is an extensive and detailed study of consumers' requirements, together with an educational campaign covering information on the development and the distribution of designs in construction that utilize the potential economies of treated wood to the fullest advantage.

It is perhaps not surprising to find that the wood preservatives most used to-day have been known for many years. The larger buyers of treated wood, such as the railway companies, to a great extent determine what preservatives will be available at the treating plants. Since the total cost of a treated stick of wood includes, among other items, the cost of transportation to and from the treating plant, labour and depreciation costs at the plant, and subsequent installation, the cost of the preservative used is frequently only a small percentage of the total cost. Therefore, although a new preservative may be cheaper than those in use, the financial saving will frequently be unattractive, since the total financial investment would be subjected to risk if the new preservative did not prove satisfactory in service. For many purposes, a preservative slightly higher in cost might successfully compete with creosote and zinc chloride if some of the disadvantages of both were overcome. Creosote generally leaves the wood dark-coloured and dirty to handle, and in some cases the odour is objectionable. Zinc chloride is a water-soluble salt and leaches out of the wood in wet locations. The ideal preservative would be one that combined the permanence of creosote with the cleanliness of zinc chloride, that would protect timber against fire, insects, and decay, and that could be shipped in a concentrated form. Such a preservative would probably compete successfully with creosote and zinc chloride, even at a somewhat higher cost.

Experiments carried out at these Laboratories indicate that poles or posts treated with a water-soluble preservative will fail at the ground-line, not so much because the preservative leaches out into the soil, but because evaporation from the top of the pole or post causes an inflow of moisture from the ground which carries the water-soluble salts up the sapwood and eventually leaves the ground-line with insufficient preservative to resist decay.

COMMON WOOD PRESERVATIVES

Creosote

CREOSOTE is obtained from coal tar by distillation. The coal tar is a by-product from the distillation of coal for the purpose of obtaining illuminating gas, or from coke ovens in which the main product is metallurgical coke. One of the remarkable features of creosote as a wood preservative is that, in spite of a wide variation in chemical and physical properties, owing to the use of different coals and methods of processing, a pure coal-tar creosote will invariably protect wood from decay if properly used.

It has been determined by trial and error over a long period of time that creosote can be used over a wider range of conditions of service than any other preservative. Owing to its resistance to leaching by water and the fact that creosote is only slightly volatile, it will protect timber submerged in sea-water from the attack of marine borers and also prevent decay in timbers exposed to the action of sun, wind, and rain. Special paints must be used if creosoted wood is to be painted.

In Canada and the United States, creosote is usually purchased in accordance with specifications issued by the American Railway Engineering Association and the American Wood Preservers' Association. The amount required for adequate protection varies with the species of wood and the conditions of service. In general, it will usually be more economical in the long run to use the maximum amount of creosote specified, rather than the minimum. For marine piling, complete full-cell saturation of the sapwood ring is required, and in species having a deep sapwood ring, an absorption of 16 to 18 pounds of creosote per cubic foot of wood will be necessary, while for species with a lesser depth of sapwood 14 to 16 pounds will be sufficient. For structural timbers, 6 to 8 pounds per cubic foot for empty-cell treatments and 8 to 10 for full-cell treatments will be suitable for timbers approximately 6 by 8 inches in cross-section. For larger and smaller timbers, the absorption should be decreased or increased respectively, in accordance with the change in ratio of surface area to volume.

Creosote-tar and Creosote-oil Mixtures

It has been customary for many years to treat railway ties with a mixture of creosote and coal tar, in order to reduce the cost of the preservative. The mixture as first used was 80 parts of creosote and 20 parts of tar. It was found by experience that such a mixture gave ample protection against decay throughout the mechanical life of the ties, so the proportion of tar is now sometimes increased to 50 per cent by volume of the mixture, and such mixtures are accepted as standard preservatives for the treatment of many materials.

Petroleum oil is also used to make up creosote-petroleum mixtures for preservative treatments. The amount of petroleum added to the creosote may vary, according to the material to be treated and its proposed use, but more than 50 per cent by volume is rarely if ever used.

Zinc Chloride

For the treatment of timber, zinc chloride is used in water solutions up to 5 per cent in strength; stronger concentrations may reduce the strength of the timber. One pound of dry salt per cubic foot of wood should be used to protect timber from decay. The strength of the treating solution is determined by the quantity of water that the timber will absorb. If the timber absorbs 30 pounds of solution per cubic foot, and it is desired to use one pound of dry salt per cubic foot, the strength of the treating solution will be $\frac{1.0}{30} \times 100 = 3.33$ per cent or 96.67 pounds of water to 3.33 pounds of dry salt. Owing to the corrosive action of zinc chloride on steel, special care is required with treating equipment.

Chromated Zinc Chloride

In recent years, sodium dichromate has been added in zinc chloride treatments, on the theory that it will help to fix the zinc chloride in the wood, and so reduce the leaching tendency of the preservative. The proportion of dichromate to zinc chloride is approximately one to four by weight of the dry salts. The recommended retention of chromated zinc chloride for treatment of timber is three-quarters of a pound of the mixed salts per cubic foot of wood.

Sodium Fluoride

Sodium fluoride is more expensive than zinc chloride, and service records do not show sufficient indications of longer life to compensate for this higher cost. However, it has the advantage of being non-corrosive to metals.

Mercuric Chloride

Mercuric chloride has been used extensively in Europe and is the most toxic of the common preservatives. Since it is highly corrosive, it cannot be used in steel treating cylinders, and, with the exception of one or two specially protected pressure cylinders, its use has been confined to steeping or soaking treatments carried out in wooden or concrete open tanks.

Copper Sulphate

Copper sulphate is corrosive to metals and is not as toxic as mercuric chloride. It is comparatively cheap and has been used extensively in France for the treatment of poles by the Boucherie process, in which a cap placed on the butt is connected by a pipe to an elevated tank containing a solution of copper sulphate. Farmers in the western provinces of Canada have treated green fence-posts by standing them upright in a tub or barrel containing a solution of copper sulphate, which travels up the green sapwood in a few days.

Tanalith

Tanalith is a water-soluble preservative mixture containing the following ingredients: sodium fluoride, 25 per cent; di-sodium hydrogen arsenate, 25 per cent; sodium chromate, 37½ per cent; dinitrophenol, 12½ per cent. The recommended retention of tanalith for treatment of timber is 0.35 pound per cubic foot of treated wood.

Zinc Meta-arsenite

This preservative is a combination of trivalent arsenic As_2O_3, 60 per cent, and zinc calculated as ZnO_2, 40 per cent, held in solution by acetic acid. After introduction of the treating solution into the wood, it is claimed that the acetic acid evaporates and deposits zinc meta-arsenite or 'ZMA' in the wood. The recommended retention of ZMA in treated timber is 0.35 pound per cubic foot.

Pentachlorophenol

Pentachlorophenol is a toxic organic chemical and for use is dissolved in petroleum oil. The concentration is usually 5 per cent, and the same absorptions can be used as for creosote. Long-term service records are not yet available.

Copper Naphthenate

Copper naphthenate is a toxic organic chemical and for use is dissolved in petroleum oil. Concentrations are usually three-quarters to 1 per cent for pressure treatment and 2 to 3 per cent for non-pressure treatment, expressed as metallic copper. The absorption can be the same as for creosote. Long-term service records are not yet available.

TREATING PROCESSES AND EQUIPMENT

THE object of all treating processes is to apply the preservative in such a manner that the increase in service life will pay for the cost of treatment and also return a profit on the money invested. The selection of the preservative to be used, and the decision as to how it should be applied, are governed by the conditions of service and the facilities available for carrying out the treatment. There are several methods of applying preservatives, some of which are undoubtedly superior to others, but each method possesses certain advantages which make it suitable for use under particular conditions. The different methods may be grouped into two divisions, namely, superficial and impregnation treatments. Superficial treatments cover the surface only with the preservative and are not as reliable as impregnation treatments, where it is forced beneath the surface to a depth of one-half inch or more. Superficial treatments are cheaper than impregnation treatments, and a minimum of equipment is required, so that their use is justified under conditions where a short added period of service life is required, or where transportation costs prohibit the use of timber treated by an impregnation process. Descriptions of the various methods of preparation and treatment follow.

Conditioning of Timber for Treatment

Since the amount of protection afforded by any preservative treatment depends greatly upon the absorption and penetration secured, it is necessary for best results that the timber should be properly conditioned before being treated. Some few treatments use end penetration or diffusion processes (discussed later) which can best be applied to green timbers. Such processes require minimum preparation of the timber prior to treatment, but they are non-standard processes which, for various reasons, are not in common use in this country and they can be used only with solutions or pastes of water-

soluble salts. For the adequate treatment of timber by all other methods, and particularly for all treatments with preservative oils, the timbers must first be peeled and then conditioned, usually by air-seasoning. This conditioning is necessary to remove from the cell cavities of the wood the free water present in all green timbers; this water would otherwise retard or even prevent the entrance of the preservative liquid. The term 'air-seasoning', when used in conjunction with preservative treatments, does not mean complete drying of the wood, but rather implies a substantial reduction of the moisture content of green timbers to a point where any moisture remaining in the cell walls of the wood will not prevent a satisfactory depth of penetration, usually with a predetermined absorption of preservative.

All timbers should be peeled before seasoning, because bark retards seasoning, thus encouraging decay; it is also almost impermeable to the preservative liquids, and for these reasons care must be taken to remove all bark before treatment.

In commercial treating plants using pressure processes, facilities are available for conditioning green or partly seasoned timbers, to render the outer layers of the wood sufficiently absorptive for subsequent treatments. Such conditioning may involve hot oil immersion or steaming followed by a vacuum, or may consist of a long period of boiling under vacuum, of which a detailed description is given later. However, despite the many advantages of using such artificial methods for the conditioning of some timbers, the method most widely used and considered the most effective is air-seasoning.

The length of time required to air-season timber will depend upon the climate and season of the year, the location and lay-out of the seasoning yard, the species and size of timbers, and the method of piling used. All these factors require careful consideration to secure for treatment sound, adequately seasoned material, free from incipient decay resulting from close piling or from over-holding, and without excessive checking caused by too rapid seasoning in dry weather.

In Central and Eastern Canada, ties cut during the winter and early spring, and properly piled to season, can be pressure-treated in the late summer and autumn months. Poles may be pressure-treated after seasoning for a similar period, though a full year's seasoning is preferable, provided the poles can be held without deterioration due to sapwood decay.

As a general rule, the drier the timber the more receptive it is to penetration. For this reason, the air-seasoning of timbers intended for treatment by superficial or non-pressure processes should be of sufficient duration to reduce the moisture content of the exterior layers to 15 per cent or less. This degree of seasoning also decreases the risk that subsequent checking may expose the untreated wood beneath lightly penetrated surfaces.

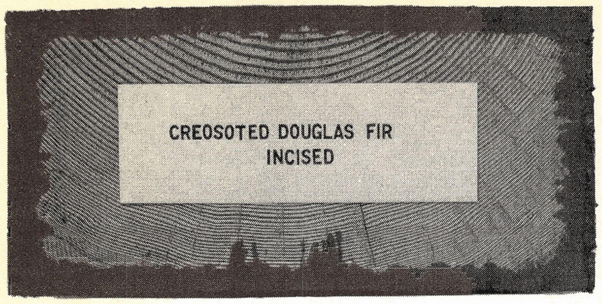
Cutting and Framing Before Treatment

In general, the penetration of preservatives into wood is not complete, and for this reason it is necessary to depend on the maintenance of an exterior treated shell, usually from one-half to one inch deep. In order to secure this, it is highly desirable that all cutting, boring, and framing should be carried out before treatment and, conforming to this procedure, there has been a continued development in recent years in pre-framing bridge and other construction timbers. It has been found that quite intricate timber structures can be shaped and fitted, and erected in the field after treatment, with little or no disturbance of the exterior treated shell.

However, when treated materials have been accidentally damaged, or when it has been absolutely necessary to trim, cut, or bore into them after treatment in such a way as to expose an untreated area, such injuries and cuts should be thoroughly swabbed or painted with at least two coats of the preservative, applied hot. Bolt holes should be poured full of hot preservative, using a bent funnel to fill horizontal holes, or using special equipment for applying creosote under pressure in holes bored in the field. With creosoted piles, the cut area exposed after the final cut-off should be brushed immediately with two liberal coats of hot creosote, followed by the application of a coat of coal-tar pitch.

Incising

Incising, though referred to as a process, is really a preparation given timbers before treatment, to secure uniform and adequate depth of penetration of preservatives. Briefly, the process consists of passing the timber through a series of studded rolls which punch rows of incisions in the faces of the timber to a depth of about one-half inch. The incisions of each row (across the face) are one inch apart, and successive rows are 6 inches apart longitudinally and staggered one-quarter inch. The penetration of preservative is greater longitudinally



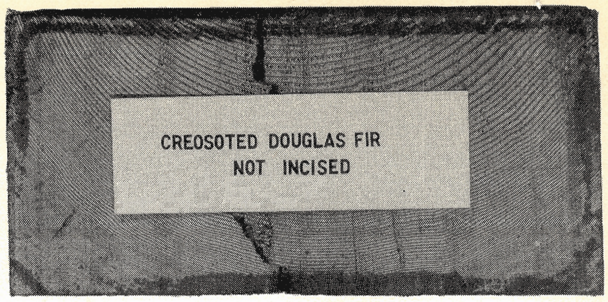


PLATE 78.—Improved Penetration Secured by Incising.

than radially, so a uniform penetration of the faces of the timber to the depth of the incisions is obtained. The process is used extensively in Canada, particularly in conjunction with the treatment of squared heartwood ties, and nearly all the large commercial pressure-treating plants are equipped with incising machines. The butts of cedar poles intended for open-tank non-pressure treatment with creosote are often incised throughout that portion of the pole lying from one foot above to two feet below the future ground-line. The incisions are about one-half inch deep, and their pattern and spacing are such as to ensure a uniform depth of penetration throughout the sapwood.

TREATING PROCESSES

Brush Treatment

THIS is a superficial treatment, usually with an oil preservative. As the name implies, the process consists of applying the preservative to the surface of the wood with a brush. The wood to be treated should be well air-seasoned and its surface should be perfectly dry. The preservative should be heated to about 190°F. before being applied, and care should be taken to brush it thoroughly into all checks, cracks, and joints. For best results, a second treatment after an interval of several hours is recommended. This method of treating wood is cheap and requires no outlay for apparatus or any skill in its application, but the protection afforded does not extend beyond the surface of the wood, and this surface, therefore, should not be broken through or worn away so as to expose the untreated interior. Should any such exposure occur, either through checking of the wood or from mechanical abrasion, the fresh surfaces should be brushed with hot preservative. In general, brush treatment may not be expected to afford protection against decay for more than a few years, but the life of timber so treated may be extended by a yearly or semi-yearly brush treating of the wood in place.

Dipping

This also is a superficial treatment, which consists of dipping or submerging the wood for a short period, usually in an oil preservative. As in the case of a brush treatment, the wood should be dry and well seasoned, and the preservative should be maintained around 190°F. during the treatment. This process requires a container or vat large enough to permit submersion of the wood, and also a means for heating the container. For these reasons, the method is not always suitable for the treatment of small lots of timber. For large quantities, however, it is more economical than a brush treatment, since dipping can be carried out much more quickly than brushing. Moreover, owing to the greater certainty of the preservative flowing into checks and cracks, the dipping treatment is preferable and, in general, gives better results than brush treatments. Any checks or abrasions that may occur during or after the placing of the treated wood in service should be well brushed with the preservative.

Steeping Treatment

This treatment, as the name implies, consists of steeping the wood in an unheated preservative solution for periods varying from one to several days. The process, though superior to a brush or dip treatment, is not as satisfactory as a hot and cold open-tank or a pressure treatment. However, steeping is suitable for the treatment of small amounts of timber in construction work, where other methods are not practical, and also for the treatment on the farm of many species of non-durable fence-posts.

Formerly the steeping process was used only to treat timbers, either green or seasoned, with water-soluble salts. When mercuric chloride was used the

process was known as Kyanizing. Of recent years it has also been used for the treatment of seasoned material with oil solutions of pentachlorophenol, and of copper and zinc naphthenates. The process requires only a tank or vat large enough to permit submersion of the wood and equipped with any simple device to prevent floating. For posts where a butt treatment only is desired, a drum or barrel sufficiently deep to allow treatment to 6 inches above the ground-line makes a suitable container for the preservative.

The duration of the steeping period varies according to the species of the wood, its seasoning, and its sapwood and heartwood content. Unseasoned timbers in a water-soluble salt solution should be left for several days, or longer if it is convenient, while peeled green posts with the butts submerged in a similar solution will have the sapwood treated in two days of good dry weather. Seasoned posts are generally left in an oil solution for one or two days. The absorption for such posts will be from less than half a pound of solution for woods with a refractory sapwood such as spruce, to perhaps over four pounds for poplar and white birch, which have readily penetrable sapwood.

Diffusion Treatments

All diffusion treatments use a toxic water-soluble salt and depend upon the ability of the salt, when applied to the surface of green or wet timbers, to diffuse into the water contained in the wood. Such treatments are used only under circumstances where standard treatments are not practical, but where some extension of the life of timbers to be used in a green condition is desired. In a diffusion process used for the ground-line treatment of poles, the salt, in powdered or granular form is mixed with the soil in contact with the pole butt. In the course of time the salt dissolves in the moisture of the surrounding soil and a certain amount diffuses into the wood as the pole butt absorbs moisture from the soil. Retardation of the subsequent removal by leaching of the soluble salt, or of a weakening of its effective concentration by the continuous travel of moisture up the pole, is sometimes sought by a simultaneous use of creosote oil and salt. Sometimes the creosote and salt preservatives are confined in a collar placed in the earth around the ground-line of the pole to direct the preservatives against the wood (see Ground-line Treatments).

A proprietary diffusion process uses several salts combined in a paste which is applied to all the surfaces of green timbers. The timbers are then close-piled, covered fairly tightly with waterproof crepe paper to prevent any drying, and left for a period of several weeks or months, during which time the salts diffuse into the timbers. When the process is applied to standing poles, the salts are mixed with creosote oil to form a paste which is applied to the excavated ground-line zone of the pole. The paste is then covered with a tarred paper bandage, and back-filling of the pole is completed.

The steeping treatment of green timbers is a diffusion process in which the salt is applied to the timbers in the form of a solution of suitable concentration. This method has had only limited use in this country, probably because of the long period necessary to hold the timbers submerged in tanks in order to secure their satisfactory treatment.

Another very old diffusion method is the treating of fence-posts or small poles by boring holes slanting downward into the wood near the ground-line, and filling them with mixtures of common salt and a toxic salt. The holes are then tightly plugged and in the course of time the salts diffuse into the wood. Penetration of the salts, however, is mainly in a vertical direction above and below the holes. If enough holes are bored to ensure complete penetration, the strength of the post or pole may be seriously affected.

It must be remembered that in all diffusion treatments very little control can be exercised over the penetration or the absorption of the preservative. For this reason, the life of timbers so treated is apt to vary considerably. Moreover, because the preservatives are water-soluble salts, the treated timbers should not be used in damp or wet locations.

End-penetration Treatments

All end-penetration treatments use a water-soluble salt and depend upon the travel of moisture in the sapwood of green round timbers. An old process, the Boucherie, has been used in Europe for many years to treat telephone poles with copper sulphate. A cell is tightly clamped over one end of the unbarked green pole and the preservative solution is led into this chamber from on overhead tank. The hydrostatic pressure of the column of liquid, or artificial pressure, gradually forces the preservative solution into the wood to replace the natural water which is

forced out of the opposite end of the pole. A modification of this method is sometimes used for treating posts by tightly fastening the open end of an old tire tube around one end of the post and then filling the tube, suspended upright above the post, with a toxic salt solution. It is practical by these methods to get complete sapwood penetration in any round green timbers for which water-soluble preservatives are acceptable.

Another method used for the treatment of green posts and small poles is to peel the round material and then stand the butts in a container of any toxic salt solution, preferably during a period of good drying weather. As the exposed tops of the timbers dry out, the water from the butts travels up the sapwood and is in turn replaced by the preservative solution. In a few days, the salt solution will travel up the pole sufficiently high to penetrate the sapwood at the ground-line zone.

This principle of absorption of salt-bearing liquid by green sapwood was utilized in a new method for the butt treatment of green poles, developed at the Laboratory (2). This process aims at fixing a relatively non-soluble preservative in the sapwood at the ground-line of a pole and is carried out as follows. An even number of holes (1⅛ inches diameter) is bored longitudinally to a depth of 8 inches in the sapwood at the butt-end of a green pole, on the lower part of which the bark has been left to a height extending above the ground-line. The number of holes bored depends upon the size of the butt and varies from 10 holes in a butt of 8-inch diameter to 22 holes in a butt of 18-inch diameter. Alternate holes are filled with copper sulphate and with sodium arsenite, two toxic water-soluble salts, after which the holes are tightly plugged with short corks and the pole is set. As the peeled top of the pole dries out, the moisture drawn up from the butt is being constantly replaced by moisture absorbed from the damp soil. The salts in the holes slowly dissolve in the moisture or water passing through the wood around the holes, and are carried up the sapwood. There is a 'fanning-out' or diffusion of the dissolved salts as they travel upwards until eventually the solutions of different salts from adjacent holes meet in the sapwood at the ground-line zone of the pole. This meeting or mixing of the different salts causes a chemical reaction which precipitates in the wood copper arsenite, a toxic salt only slightly soluble in water. This means that the new salt will tend to remain in the wood, owing to its low solubility, and therefore will give protection against decay for a much longer time than will more soluble salts. The latter, because of gradual travel into the pole top, eventually leave the pole unprotected at the ground-line zone.

Ground-line Treatments

There are millions of untreated wood poles, mostly cedar, in service in lines in Canada. For various reasons, it was not possible to treat these poles by any standard process before installation, nor is it possible to treat a large number of new installations. However, the poles can be treated in place by the application of preservatives to the ground-line section. Though such treatments do not give complete protection to the entire butt section of standing poles, yet they are of a certain value in retarding decay at the ground-line, where decay first appears and progresses most rapidly, and where strength reductions occasioned by loss in diameter owing to decay are most serious.

Ground-line treatments are not as efficient as standard pole treatments and should not be used for the treatment of poles of non-durable species with deep sapwood. They are recommended only for use on untreated cedar poles where conditions do not permit the standard treatment prior to installation. The treatments may be applied to old or new poles, though naturally the results are more satisfactory on installations where the sapwood of the pole is still unweakened or destroyed by decay. There are several methods of ground-line treatment, some proprietary, but all methods aim at surrounding a section of the pole from a few inches above the ground-line to 12 or 18 inches below with preservative, part of which is eventually absorbed by the sapwood of the pole.

Treatments are generally carried out by making excavations around the standing poles to a convenient depth, usually about 2 feet, or the backfilling of new installations may be left uncompleted to the same depth. A collar or band filled with a carrier (sand, peat, or earth) saturated with the preservative is then secured around the section of the pole extending below the ground-line, and backfilling is completed. In the course of time, the preservatives are absorbed by the sapwood under the collar, and even travel for some inches into the sapwood above the ground-line and to a depth of

several inches below the bottom of the collar. One method dispenses with a collar or band and saturates with preservatives the soil loosened to a depth of about 12 inches around the pole butts.

The preservatives used in most ground-line treatments are creosote oil (either used alone or in combination with different water-soluble preservative salts), and oil solutions of copper naphthenate. The water-soluble salts penetrate into the sapwood beyond the depth of creosote penetration, especially in damp soil, and may even diffuse into the heartwood, which is never penetrated by the oil.

Extensive tests carried out at Ottawa by the Laboratory over a period of eight years showed that six different processes of ground-line treatments were all effective in inhibiting decay at the ground-line of old and new cedar pole stubs for a period of six years, and that the penetration secured by a combined creosote and salt treatment gave promise of greatest benefits in prolonging the life of cedar poles.

For a combined creosote-salt treatment the amounts of preservatives used are 1 gal. to 2 gals. of creosote (depending on the size of the pole) and 1 lb. to 1½ lbs. of a water-soluble preservative salt.

Open-tank Treatment

This method of treatment derives its name from the character of the equipment required, namely, two open tanks of any convenient size and shape. Figure 27 illustrates the application of this process in the butt treatment of fence-posts. The posts are placed upright in creosote to a depth of 6 to 12 inches above the ground-line and allowed to stand for from one to several hours, during which time the temperature of the creosote is maintained at about 220°F.[1]. This hot bath partly volatilizes the moisture in the wood and expands and forces out of the wood-cells a certain amount of air and moisture. The posts are then removed from the hot tank and the butts are immediately submerged in a tank of cold oil. This cools and contracts the air and moisture in the wood, which draws in creosote; instead of using a separate cold tank, the posts may be left in the hot tank until it is cool. The duration of the hot and cold baths depends on the species of timber and the dimensions of the posts under treatment. The air-seasoned sapwood of some species of timber, such as red pine, will readily absorb creosote during the cold bath, and more difficulty will be experienced in preventing excessive consumption of creosote than in obtaining complete penetration of the sapwood. With the exception of spruce, hemlock, and a few other species, sufficient penetration of creosote in the sapwood can be obtained, in round posts, to increase the average service life from five years (untreated) to twenty years.

[1]It is advisable to use a creosote in which the distillate does not exceed 25 per cent up to 235°C.

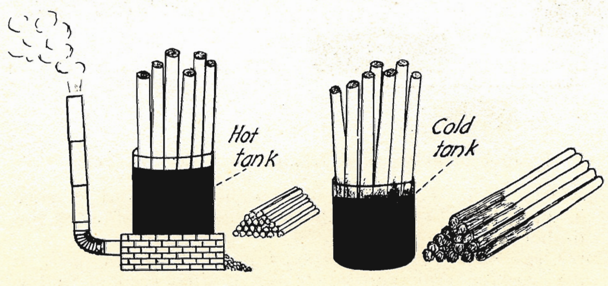


FIGURE 27.—Open-tank Treatment of Fence-posts.

Open-tank treatments can also be used for the treatment of round posts or poles with water-soluble preservatives such as zinc chloride or sodium fluoride.

The open-tank treatments have not been extensively used for the treatment of heartwood timbers, since the heartwood is much more refractory, in nearly all species, than the sapwood.

Full-cell Process

This method of treatment is a pressure process, often referred to as the "Bethell" process, after John Bethell, who patented it in England in 1838. Either green or seasoned material may be treated by this process, although best practice recommends that the wood be well air-seasoned before treatment. The timber is loaded on to small steel cars, or "buggies", which are then run into a long horizontal steel cylinder (B in Fig. 28). This cylinder or retort is equipped with steam coils for heating the preservative, and has a cast-steel door fitted to a cast-steel flange, which is riveted to the shell of the retort. The retort varies from 6 to 8 feet in diameter and from 80 to 150 feet in length. After the retort door is closed and bolted, the timber, if green, is exposed to steam pressure—usually not exceeding 20 pounds per square inch—for several hours. With air-seasoned material, the steam treatment is omitted. A vacuum is then created in the cylinder by means of a pump (D in Fig. 28), and maintained for one or more hours. Without breaking the vacuum, the preserva-

tive, which has already been heated by steam coils in the working tank (A in Fig. 28) is then drawn or pumped into the cylinder until the latter is full. Pressure is then built up and maintained in the cylinder by means of the pump (E in Fig. 28) which forces the preservative from the working-tank into the cylinder. The pressure varies between 100 and 180 pounds per square inch, and is maintained until the gauges or scales show that a predetermined amount of preservative has been forced into the wood, or until it has been treated to saturation. During this pressure period the temperature of the preservative in the cylinder is maintained at approximately 190°F. The pressure is then released and the oil is pumped from the cylinder back to the working tank. The charge of timber is then allowed to drip for a short period (many operators apply a final vacuum to hasten the drip and dry the timber), after which it is removed from the cylinder.

The full-cell process may be used to treat timber with creosote or with mixtures of creosote and other oils, or with solutions of water-soluble preservatives. If the treatment is carried out with the water-soluble zinc chloride, it is known as the Burnett process, from a patent granted to William Burnett in England in 1838. The full-cell process has proved to be very effective in prolonging the life of timbers. With creosote oil, however, the process is relatively expensive, owing to the large amount of oil absorbed. For the protection of timbers against marine borers, this heavy absorption is very desirable, but for other purposes a diminution of the amount of creosote retained by the timbers would still give satisfactory results, although there is a relation between the amount of creosote absorbed and the extension of service life. A reduction in the amount of creosote used may be secured by empty-cell treatments, which are described below.

Lowry Process

This process is named after C. B. Lowry, to whom was granted in 1906 a United States patent. This also is a pressure process and it differs from the full-cell process in the order of application of pressure and vacuum. Air-seasoned timber is loaded on trams or buggies and run into the treating cylinder, which is then closed and filled from the working tank with oil heated to about 190°F. The oil pump (E in Fig. 29) builds up in the cylinder a pressure of from 100 to 180 pounds per square inch, and pressure and temperature are maintained until a certain absorption of preservative by the wood is secured. After the pressure is released, the oil is pumped back to the working tank, and a vacuum of 24 to 26 inches of mercury is then created in the cylinder by a vacuum pump (D in Fig. 29). After the vacuum is broken, the recovered oil is pumped back to the working tank and the charge of timber removed. The Lowry process, which recovers some of the free oil from the wood cells, thus leaves the cells to some extent empty of creosote and is, therefore, often described as an

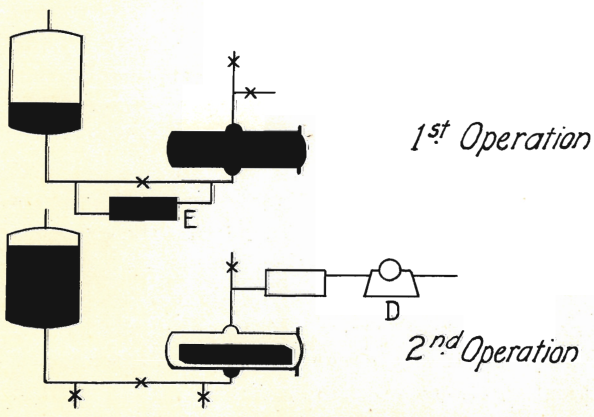


FIGURE 28.—Pressure Treatment, Full-cell Process.

1ST OPERATION—Vacuum is created and maintained on the timber in the closed cylinder.
2ND OPERATION—While maintaining the vacuum the cylinder is filled with hot oil, after which pressure is applied and maintained until the desired absorption is secured.

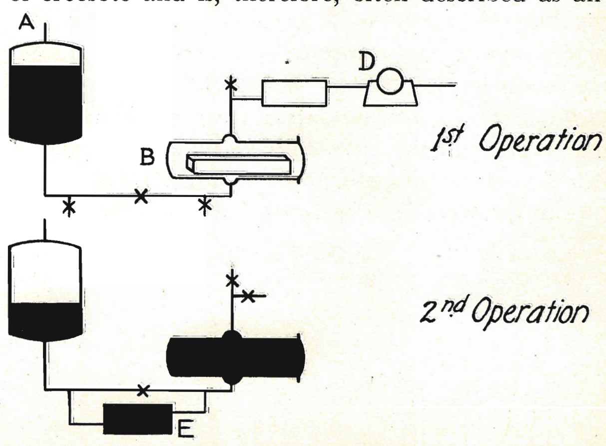


FIGURE 29.—Pressure Treatment, Lowry Process.

1ST OPERATION—Cylinder is filled with hot oil, and pressure is applied until the predetermined absorption of oil by the timber is secured.
2ND OPERATION—Oil is pumped from the cylinder back to the working tank and a vacuum is then created in the cylinder. After the vacuum is broken the cylinder door is opened and the charge of timber is removed.

empty-cell process. The process is extensively used for the treatment of railway ties, and the ratio of oil absorbed to depth of penetration is smaller than in the Bethell full-cell process.

Rueping Process

This pressure process, developed in Germany, was patented in the United States in 1902. Its object is to obtain a deep penetration of creosote oil in timber, and then to withdraw a percentage of this oil before the timber is removed from the cylinder. It is, therefore, essentially an empty-cell process. The timber to be treated should, preferably, be air-seasoned, though green timber may be treated after it has been subjected to conditioning by steam and vacuum in the cylinder, or has been treated by boiling under vacuum in oil.

The cylinder is filled with compressed air at a pressure of between 30 and 60 pounds per square inch by an air-pump (F in Fig. 30) and, after one-half to one hour, hot creosote from the working tank is forced into the cylinder, displacing the compressed air. When the cylinder is filled with creosote, the pressure is raised to 125 to 200 pounds per square inch. During this oil-pressure period, the temperature of the oil is maintained at about 190°F. When the predetermined absorption of oil, known as the gross absorption, has been secured, or when the wood will absorb no more oil, the pressure is released, and the oil is pumped back to the working tank. With the release of the pressure, there occurs an exudation of oil from the wood, caused by expansion of the air compressed in the wood cells during the initial air-pressure period. This expansion may expel from the timber as much as fifty per cent of the gross absorption of oil, which the oil pump returns to the working tank. A final vacuum of at least 20 inches is then created in the cylinder. This increases the expansive force of any compressed air remaining in the wood, and thus expels still more of the oil. The vacuum is continued until the drip of oil from the wood ceases and the surface of the timbers is fairly dry, when the charge of wood is withdrawn. The amount of oil then remaining in the treated timbers is known as the net absorption.

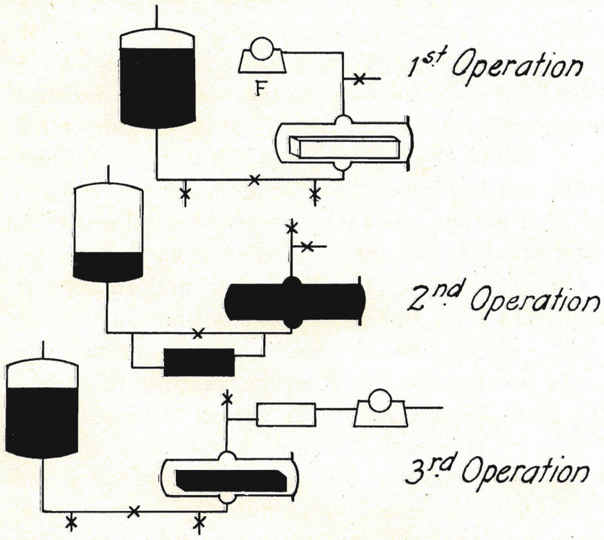


FIGURE 30.—Pressure Treatment, Rueping Process.

1ST OPERATION—Air pressure is applied and maintained on charge of timber in cylinder.
2ND OPERATION—Compressed air in cylinder is displaced, without reducing the pressure, by hot oil. Pressure in cylinder is then increased and maintained until the desired gross absorption is secured.
3RD OPERATION—Pressure is released, oil is then pumped back to working tank, and a vacuum is created and maintained in the cylinder; when the vacuum is broken, the cylinder is opened and the timber removed.

From the foregoing description of the Rueping process, it is evident that penetration of the wood is accomplished with a minimum consumption of creosote oil. With round timbers of non-refractory species, a recovery of 70 per cent of the gross absorption may be secured by manipulation of the initial air and oil pressures. The process is quite extensively used, but whether it is equal to the full-cell process in the degree of protection afforded timber against decay is a debatable question that must be considered in conjunction with the cost of the oil, the proposed uses of the treated material, re-use value, and other points.

Boiling Under Vacuum

This is really not a treating process, but is a method of preparing green or partially seasoned timber for treatment by conditioning the timber in the treating cylinder. The method is used only in conjunction with treatments with a preservative oil. It is generally recognized that it is not possible to force a preservative into wood whose cells are already full of water. Green wood contains a considerable quantity of water, sometimes amounting to over 50 per cent of the weight of the green wood, or over 100 per cent of the weight of the oven-dry wood. Before a preservative oil can be forced into green timber, a large portion of this contained water must first be removed; in other words, the moisture content of the wood must be reduced.

Some species of timber suffer a considerable reduction in strength when processed at high temperatures. In order to vaporize and remove the moisture in the wood (that is, to condition it artificially), and to do this without having recourse to high temperatures, the wood is boiled in oil under a vacuum as follows:—

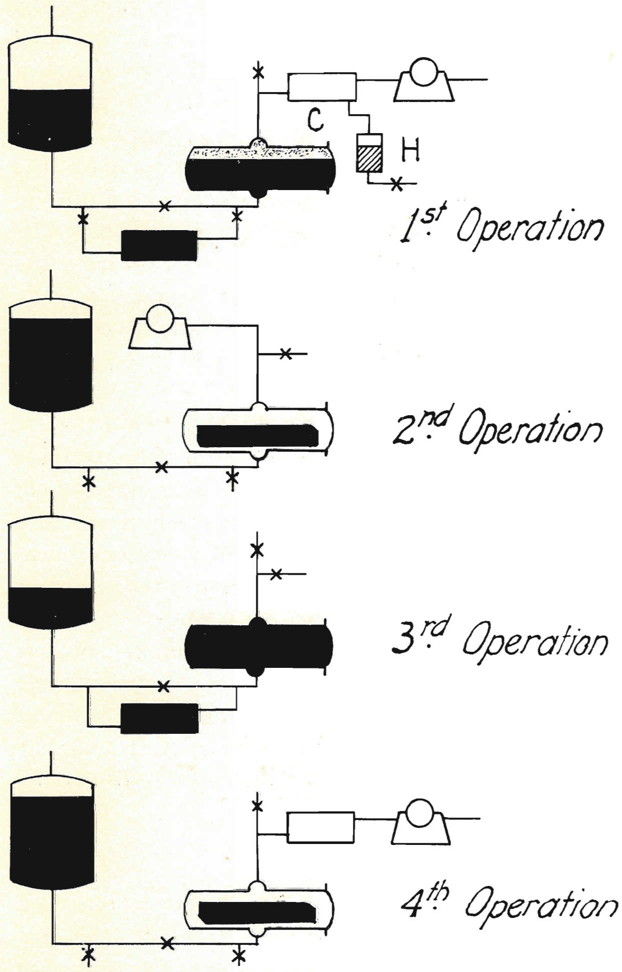


FIGURE 31.—Seasoning Green Timber by Boiling under Vacuum, Followed by a Rueping-process Pressure Treatment.

1ST OPERATION—The cylinder is filled with hot oil to cover the timbers, and a vacuum is created and maintained until the flow of condensate from the moisture in the wood (caught and measured in the drip tank H) is sufficiently reduced.

2ND OPERATION—The oil is blown from the cylinder to the working tank, and air pressure is then applied and maintained on the charge of timber in the cylinder.

3RD OPERATION—Compressed air in the cylinder is displaced, without reducing the pressure, by hot oil. Pressure in cylinder is then increased and maintained until gross absorption is secured.

4TH OPERATION—Pressure is released, oil is pumped back to the working tank, and vacuum created and maintained in the cylinder. After the vacuum is broken, the cylinder is opened, and the charge of timber removed.

The green wood is placed in the cylinder, which is then closed and filled until the material in the cylinder is covered with oil previously heated to about 200°F. in the working tank. This temperature will drop to about 180°F., or lower, when the oil comes into contact with the wood. A vacuum is then created in the cylinder, and is maintained throughout the conditioning period, during which time the temperature in the cylinder is held between 180° and 220°F. As the timber becomes heated by the oil, the moisture in the wood vaporizes under the reduced pressure and is drawn off through a condenser (C in Fig. 31) by the vacuum pump. This vaporization of the water causes foaming within the cylinder, and to prevent this foam (a mixture of water vapour and liquid oil) from being carried into, and quickly filling the condenser, the vapours are led through a tall gooseneck piping mounted vertically on the cylinder and extending to a height of about 30 feet.[1]

The conditioning continues until the material is sufficiently heated, and enough water has been removed to permit proper penetration of oil by a subsequent pressure treatment. This point may not be reached until after a long period—often 20 hours—and it is determined by examination at intervals of the amount of condensate in the drip tank (H in Fig. 31). The foaming in the cylinder, which is violent at the beginning of the operation, subsides in intensity after a few hours. After the timber has been sufficiently conditioned, and if a full-cell treatment is desired, the cylinder is completely filled with oil without breaking the vacuum. Pressure is then applied and the treatment is carried out at an average pressure of 175 pounds, and an average temperature of 180°F., as already described in the outline of the full-cell process. If the timbers are to be treated by the Rueping process (Fig. 31). the cylinder is emptied of preservative after the boiling-under-vacuum period. The timbers are then subjected to air pressure of sufficient intensity and duration to provide, in conjunction with a final vacuum, for the ejection of surplus preservative, and to ensure the retention and proper distribution of the stipulated amount of preservative to be left in the timbers. The preservative is then introduced into the cylinder, and the treatment carried out as already described.

[1]A device for breaking up the foam, developed experimentally at the Forest Products Laboratories, permits the cylinder to be filled to within a few inches of the top, the vapours only being allowed to pass into the condenser.

Conditioning by boiling under vacuum is practised extensively in Pacific Coast plants engaged in the treatment of green Douglas fir ties, timbers, and piling. It is not used to the same extent in Central or Eastern Canada, where all material is generally air-seasoned before treatment.

DURABILITY OF TREATED AND UNTREATED TIMBER

THE question of the relative durability of treated and untreated timbers of various species, used for different purposes, under varying conditions of service, and treated by various methods with different preservatives, covers a very wide field. A complete review of recorded tests is extremely difficult, owing to a scarcity of detailed records of some products, and a multiplicity of records of others which show varying results. The most complete records available are those covering the life of treated and untreated railway ties. These are subjected to considerable mechanical wear, which affects their service life. It would be expected that other wood products not subject to such wear, such as telephone poles and bridge timbers, will have a longer life than ties; records show this to be the case. In Canada, the life of untreated railway ties is approximately as follows: jack pine, 5 to 8 years; hemlock, 5 to 7 years; Douglas fir, 6 to 8 years; beech, yellow birch, and hard maple, 3 to 4 years. When treated with creosote, all these ties have an average life of between 20 and 25 years, on the basis of tests of ties in service in Canadian lines. Zinc chloride treated ties have a shorter life of approximately 16 to 18 years. Telephone poles and bridge timbers treated with creosote may be expected to last 35 years. Round fence-posts treated with creosote will last from 16 to 30 years, this period depending on (1) the care taken to secure a complete penetration of the sapwood about the ground-line in the case of species of durable heartwood and thin sapwood, such as cedar, and (2) the securing of complete full-length sapwood penetration in species of lower durability.

ECONOMICS OF TREATMENT

IN comparing the cost of treated and untreated timber, probably the best method is to use the cost of the timber in place, including the cost of erection, and calculate the annual charge. This is equal to simple interest on the cost of the material in place, plus an amount to be set aside annually at compound interest to provide for replacement. Suppose, for example, that a culvert, or a small bridge, is to be constructed with treated or untreated wood, and it is desired to know which is the more economical. The comparative charges may be calculated as under.

Two factors which have not been considered in the calculations below are maintenance and salvage

	UNTREATED	TREATED
2,000 bd. ft. at $40 per M. ft. b.m.	$80.00	$80.00
Treatment with 8 lb. of creosote per cubic foot, at $25 fer M. ft. b.m.		$50.00
Cost of framing and erection*	$80.00	$80.00
Total cost in place	$160.00	$210.00
Service life	8 years	30 years
Rate of interest	5 per cent	5 per cent

$$\text{Annual charge} = S\left(r + \frac{r}{(1+r)^n - 1}\right)$$

	UNTREATED	TREATED
where S = cost in place	$160.00	$210.00
r = rate of interest (5 per cent)	.05	.05
n = number of years	8	30

$$\text{Annual charge untreated} = \$160.00\left(.05 + \frac{.05}{(1.05)^8 - 1}\right) = \$24.00$$

$$\text{Annual charge treated} = \$210.00\left(.05 + \frac{.05}{(1.05)^{30} - 1}\right) = \$13.65$$

Therefore, an investment of $50.00 for treating saves ($24.00 – $13.65) × 30 = $310.50 in 30 years.

**For treated wood, the framing should be carried out at the treating plant before treatment.*

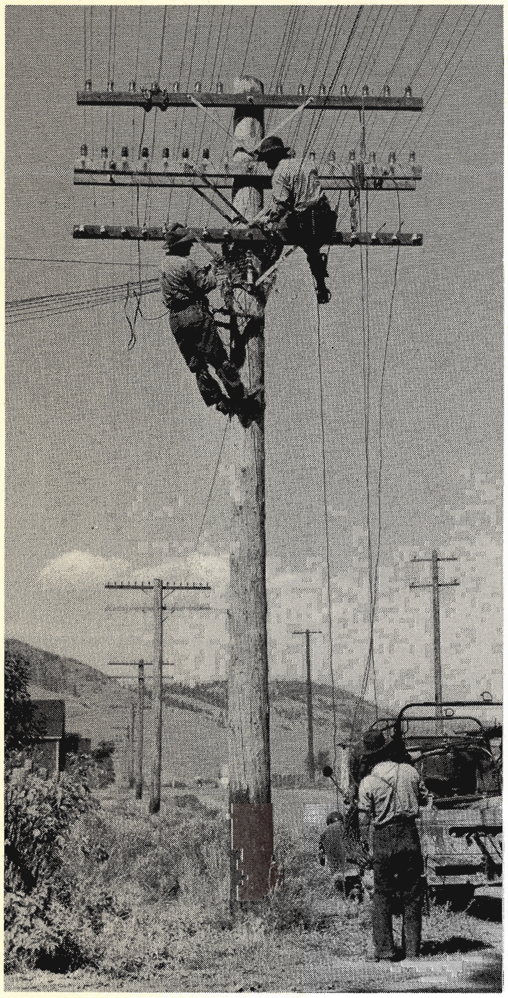


PLATE 79.—Creosoted Telephone Poles.

PLATE 80.—Pressure-creosoted Water Tower.

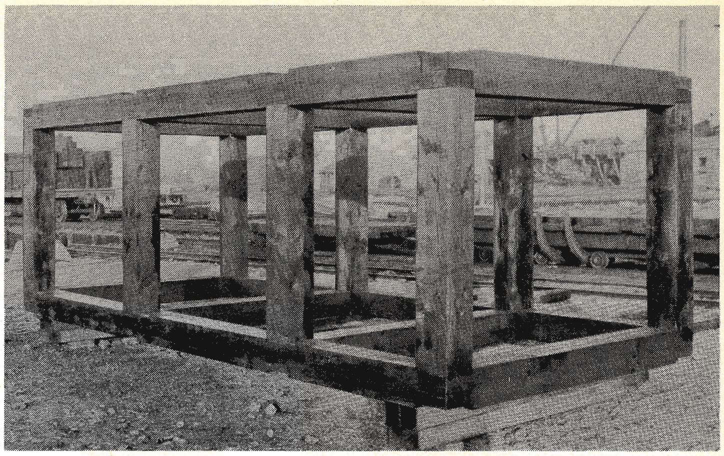


PLATE 81.—Pressure-creosoted Mine Shaft Timber.

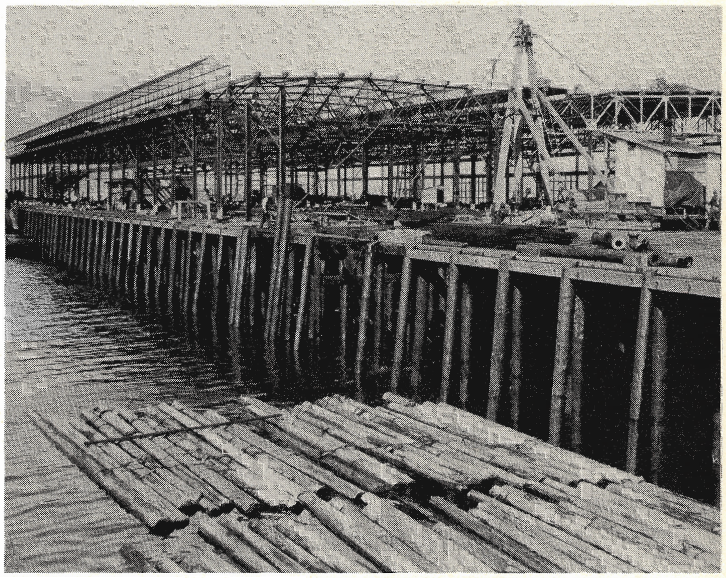


PLATE 82.—Canadian National Railway Pier, Vancouver, B.C.—
Creosoted piling, zinc-chloride treated floor.

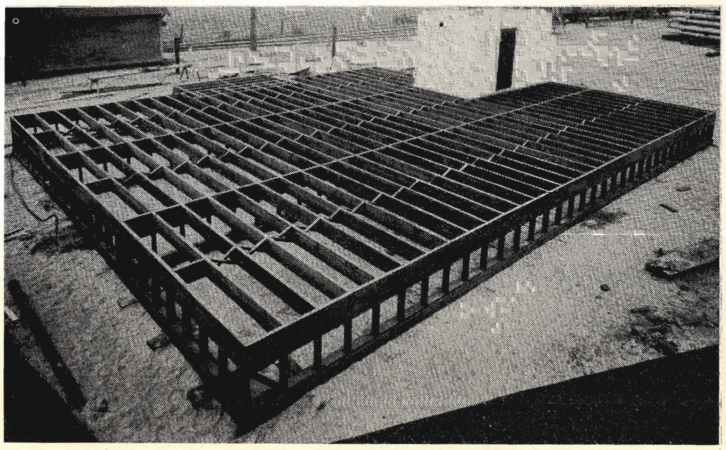


PLATE 83.—Treated Timber Foundation for Office Building.

value. If these are included, the balance in favour of treated wood will usually be increased. Although treated wood, used in a similar manner to untreated wood, will usually be more economical under conditions favourable to decay, the maximum saving resulting from the use of treated wood will occur when the design of structures is altered so as to take full advantage of the fact that treated wood is practically a new building material, and may be safely used in a manner that is not practical in the case of untreated wood.

Another feature of the economy of the use of treated wood is that species of low natural durability, which are available at a lower cost, can be utilized as successfully as species that are naturally durable.

Railway Ties

The price of practically every commodity used in Canadian homes is affected by the cost of railway transportation, and, since the cost of ties represents a substantial percentage of that cost, the financial saving resulting from the use of ties treated to resist decay actually makes a substantial contribution towards keeping down the cost of living. The treated wooden tie has proved to be the most suitable and economical form of rail support. If wooden ties could not be treated to resist decay, railway companies would long ago have been forced to adopt a substitute for wood. Figure 32 shows the extent to which treated ties have been used in Canada.

The following Canadian species are used for ties, both treated and untreated: jack pine, lodgepole pine, red pine, white pine, spruce, eastern and western hemlock, Douglas fir, and oak. Tamarack and cedar are used untreated. Yellow birch, hard maple, and beech are used when treated.

Poles

In Canada, poles of untreated eastern and western cedar have to date proved very satisfactory. However, changing conditions, such as street and highway widening, or increased power loads which necessitated the use of larger poles, have meant that poles have frequently had to be replaced even though they still had years of useful service life in them. An era is now beginning, however, in which these conditions are much more stabilized, and the potential 35-year life of treated poles is assuming greater importance, as is also the superior strength and better form of species such as Douglas fir and the

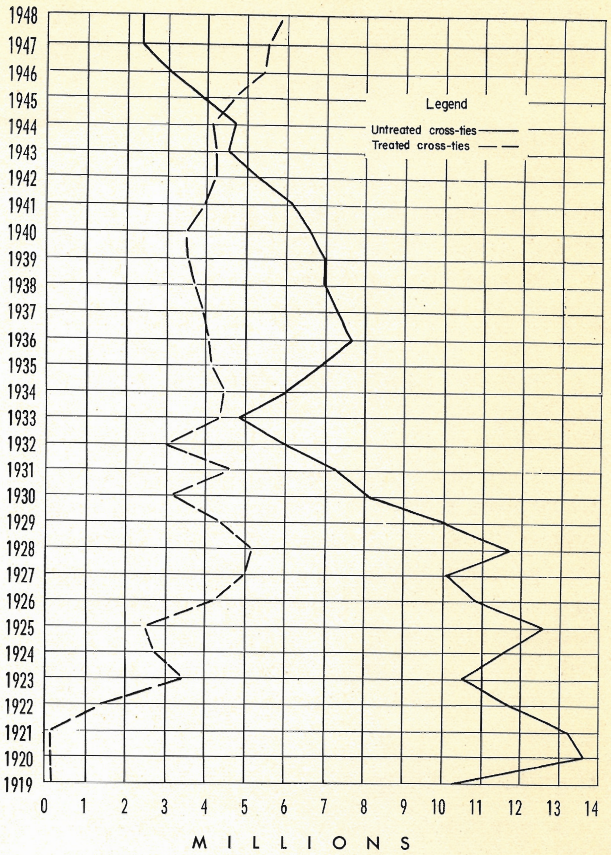


FIGURE 32.—Treated and Untreated Cross-ties Placed in Track in Canada.

pines. These species have a low natural durability, which is overcome by proper preservative treatment, and there has been during the past ten years a great development in full-length creosote treatment of such poles.

Lumber and Structural Timbers

The preservative treatment of lumber and structural timbers has been increasing each year. Component parts of buildings, such as sills, joists, subflooring, nailing strips, rafters, and roofing plank, are benefited by treatment. In parks, many structures may be constructed of treated wood, such as stadium seats, bleachers, tool sheds, and amusement structures, such as scenic railways. On farms, small outbuildings, chicken houses, fences, and gates will present a neat and tidy appearance, during long years of service, if constructed of treated wood. For irrigation projects, treated flumes, pipes, gates, and diversion boxes are serviceable and economical. There are also numerous miscellaneous uses for

treated wood, such as retaining walls and cribbing, septic tanks, ice-houses, loading platforms, water-tanks, scows, and garden edgings.

Marine Structures

Timber construction is very suitable for port and harbour structures, the chief advantage being that, as conditions change and larger wharves are required, wooden wharves can be altered and enlarged easily. The greater resiliency of wood, as compared with stone or concrete, is also of very definite value in connection with the berthing of ships. With regard to permanency, most structures are out of date before treated timber has reached the end of its useful service life. In sea-water, timber must be protected from marine borers, and since water-soluble preservatives will, of course, be rapidly leached from the wood, the choice of preservative is more limited than in the case of protecting wood from decay. Creosote, however, has been found to be quite satisfactory, provided an adequate quantity is used. Fourteen to eighteen pounds per cubic foot is required.

Foundation Piling

It is probable that, in the future, treated piling for foundations will be used more than in the past. Formerly, the use of untreated wooden foundation piles necessitated cutting them off below low-water mark, in order that they would always be saturated with water and thus be immune to decay. Creosoted piles buried in the earth and capped with concrete footings are protected from decay, irrespective of the water level, and are being used increasingly for permanent construction.

Mine Timbers

Mining operations require such enormous quantities of timber that the question of proximity assumes great importance; long hauls add appreciably to the cost of operation. Preservative treatment means that readily accessible supplies will remain accessible over a much longer period, and has the additional advantage that accessible species of low natural durability may be used when treated.

In the development of a mining property, if it were decided to utilize treated timber wherever there was a probability of a life of 10 to 20 years being required, and if this policy were enforced from the start of operations, the resulting economies would prove to be very interesting to the owners. In other words, in addition to the treatment of mine timber proper, offices and other buildings could in many instances be constructed with foundations of treated wood more cheaply, and with greater salvage value, than with any other type of construction.

In nearly every mine there are certain permanent or semi-permanent timbers that can be treated to advantage, such as shaft and slope timbers, entry timbers, gangway timbers, ties, and poles.

The preservatives most commonly used for the treatment of mine timbers are zinc chloride and creosote. Others that have been used are sodium chromate, mercuric chloride, zinc sulphate, and various arsenical compounds.

WOOD PAINTS AND COATINGS

ONE of the characteristics of wood is that it tends to pick up or lose moisture when exposed to conditions of fluctuating relative humidity. To overcome this variation entirely constitutes one of the most difficult problems pertaining to the use of wood. When the moisture content of the wood is below the fibre-saturation point, this gain or loss of moisture is accompanied by swelling or shrinking of the wood. In order to prevent, as far as possible, changes in dimension, it is necessary to cover the wood with moisture-retardant coatings, since, in most cases, it is not possible to control the relative humidity of the surrounding air. The term "moisture-retardant" is used advisedly to describe such coatings, because none of them are actually moisture-proof. The most suitable coatings are, however, sufficiently effective to slow down changes in the moisture content of the wood, allowing it to maintain a moisture balance closely equivalent to the corresponding average relative humidity of the surrounding air. Wood does not follow sharp fluctuations, but generally conforms to the average humidity, and when this average changes from season to season the moisture content of the wood also changes.

Wherever the use of seasoned wood is necessary or advisable, as is the case in the majority of uses, the wood should be dried or seasoned to a moisture content corresponding to the average that will exist under its service conditions.

The coatings used or suggested for application to wood in order to retard the absorption of moisture include oils, waxes, wood-fillers, spirit and oil varnishes, enamels, lacquers, paints, and metallic coatings

of leaf or powder. Though all these groups are effective, the degree of effectiveness varies considerably, even within the same group. This is to be expected, and is attributable to the variations of ingredients, and the different proportions of the same ingredients which may be incorporated in any one coating.

Of all the coatings recommended for the protection of wood against changes in moisture content, the application of aluminium leaf, between other coatings, is most effective. For exterior use, the aluminium leaf is generally applied between two coats of white-lead paint. The effectiveness of this combination of coatings increases notably with a second or third application of the leaf. This is rarely practical, as even a single application of the leaf is a relatively long and expensive process, although worth while for important work.

Of more practical importance is the use of aluminium powder mixed with varnishes or paints. Such mixtures are almost as high in moisture-retardant effectiveness as are the leaf coatings, and their application presents no difficulties. The effective protection increases, of course, with the number of coatings and with the use of a higher percentage of aluminium powder.

Of the many varnishes available, spar varnishes are usually recommended as good moisture-retardant coatings for wood, particularly for situations where a high resistance to moisture is required. These varnishes are sometimes known as marine varnishes, owing to their general use in situations exposed to marine atmosphere. They are typical "long-oil", china-wood-linseed varnishes containing a large proportion of drying oils relative to resin content. This excess of drying oil increases the toughness and elasticity of the film. Though not waterproof, they are fairly effective in preventing moisture changes in wood.

Varnishes are applied either by dipping, spraying, or brushing. Effectiveness of a varnish as a moisture-resistant coating depends on the thickness, adhesion, and continuity of the film. A normal thickness of film is obtained by the application over new wood of three coats of varnish, adequate drying time being allowed between applications. A greater thickness than this will sometimes cause wrinkling of the film and consequent loss of adhesion and continuity. For re-varnishing, the surface should be well sanded and free from dirt, scale, and other foreign matter. The application of one or, at the most, two coats of varnish usually affords sufficient protection from moisture.

Paints and enamels are manufactured by grinding various proportions of pigments together with drying oils, varnishes, and synthetic resin vehicles. The addition of pigments increases the moisture-retardant properties of the coating.

The great increase in research in the protective coatings field has led to the development of high-quality moisture-retardant paints, varnishes, lacquers, and enamels for use on wood. To ensure that the correct protective coating is used, a series of paint specifications has been set up by the Canadian Government Specifications Board as a guide to users.

Water Repellants

Within recent years, a line of commercial water-repellant dips and sealers for wood have appeared on the market. These vary considerably in their power to repel water, some of the better ones being up to 80 per cent effective. In other words, they reduce swelling of a treated piece of wood 80 per cent as compared with that of a matching untreated piece of wood. Many of the more effective products are better than raw undiluted linseed oil, which rates about 50 per cent, or coal-tar creosote, which rates about 42 per cent, by the same method of testing. A distinction is now made between water-repellants and sealers. A water-repellant liquid should penetrate fairly deeply into the wood, even when applied by non-pressure methods; it should not swell the wood during application, and after drying should leave the wood essentially unaltered in odour, colour, smoothness, and dimensions. A wood sealer, on the other hand, penetrates into the wood just enough to leave no coating on the surface, and on drying leaves the wood cells and pores at the surface largely occupied by non-volatile ingredients, so that the surface will exclude moisture, and be non-absorptive of paints or other liquids. In some cases, the repellants and sealers contain a fungicide or insecticide. Commonly used fungicides are the chlorinated phenols and phenyl-mercury oleate (1).

WOOD FINISHING

WOOD paints and coatings are used for the protection or decoration of wood surfaces. Coatings should therefore be selected on the basis

of the particular use intended, and the conditions under which the coated surfaces are expected to serve. It is necessary to consider the painting of wood surfaces from two aspects, (a) the painting of new wood, and (b) maintenance.

Exterior Painting

(a) Painting of New Wood

Moisture in wood, and especially all moisture which builds up in the wood after application of the paint, is considered to be the greatest cause of failure of exterior paints and coatings. No surface should be painted unless it is sufficiently dry, and the wood properly seasoned to a moisture content not greater than 12 per cent.

Properly milled wood presents a good surface for exterior painting. All sapwood streaks and knots should be sealed with a shellac sealer or an exterior aluminium paint. A thin continuous coating of either of these provides the best sealing properties and results in the best adhesion of subsequent paint coatings. A blow-torch and scraper, or a solvent wash, should be used to remove excess resin apparent on the wood surface. The prime coat is then applied by brushing, and after it is dry, nail holes, knot holes, etc. should be filled with putty. Openings around sills, dormers, and sashes should be caulked to prevent entry of moisture into the wood behind the paint coating. It is usual in new work to apply two finish coats either by brush or spray.

(b) Maintenance

Re-painting should be done while the old paint is in good condition. The surface should be prepared by sanding with a medium-grade sandpaper to remove all loose particles, followed by washing to obtain a clean surface. One finish coat is usually sufficient, unless the old surface is in poor condition.

To re-paint a surface on which the old paint is in a state of disintegration, the surface may be prepared by using paint and varnish remover, by the use of a blow-torch and scraper, or by wire-brushing, depending upon the degree of disintegration. Washing with a dilute solution of tri-sodium phosphate will generally remove any mildew contamination.

Interior Painting

(a) New Wood

It cannot be stressed too strongly that the wood should be well seasoned, and that surfaces to be painted should be thoroughly dry. The moisture content should not be greater than 12 per cent, and preferably should be of approximately the average moisture content to which it will be subjected in its surroundings. The surface should be sanded smooth before priming. When the primer is thoroughly dry the necessary puttying should be done. Two coats of finish are usually required for a good paint job. If enamel is used, it is advisable to use enamel undercoating.

When clear varnish coatings are to be applied to flooring, plywood panelling, or hardwood trim, there are several finishing operations which should be observed. The first and most important step in any finishing procedure is to ensure that the surface to be coated is as free as possible from foreign substances, discoloration, and sander dust. Hardwoods, especially the open-pore types such as oak, walnut and ash, discolour quickly and deeply, even in contact with clean water. These species should therefore be finished as soon as possible after they have been installed. If discolorations are present, spot bleaching with oxalic acid (1 part in 12 parts of water) may remove the stain. Thorough washing of the area with cloth and water must follow in order to remove any excess chemical, if damage to the finishing coats is to be avoided.

A "seal-coat" of shellac varnish (one part standard white shellac, reduced with one part of methylhydrate) is brushed over the surface. This seal-coat prevents penetration of the wood by oils and resins of subsequent coatings, and thus aids in preventing discoloration caused by their darkening.

It is usual to apply two coats of the finishing varnish, allowing the proper drying period between coats.

Proprietary materials have been formulated especially for painting building boards, such as wall-board, pulp-board, fibreboard, and pressed wood, all of which are essentially wood products.

(b) Maintenance

Interior surfaces are generally contaminated by wax, grease, or oil films, and if this contamination is not removed slow drying and poor adhesion will result. These films can be removed by washing with a strong soap solution, or with solvent or thinner.

Any loose finish should be brushed or scraped off, the surface sanded smooth, and bare spots primed. Sanding dust can be removed by the use of a tack-rag (this may be made by damping a cloth with slow-dry-

ing varnish and allowing it to become tacky before use). Any necessary putty work is done. The application of one finish coat of paint or enamel is usually sufficient.

FURNITURE FINISHING

Materials

The finishing of furniture and special wood structures presents numerous problems. This is particularly so in all cases of clear finishes where the figure of the wood remains visible. A variety of materials* is required to obtain the desired results. The most used are: stains (water, oil, or spirit); wood fillers; bleaches; varnishes; paints or enamels.

Methods

Most furniture is finished on a production-line basis and the procedure used is determined in advance by the manufacturer and the finish supplier. However, the following basic procedure should give satisfactory results.

1. Bleaching.— Dark streaks and spots, and certain naturally occurring colourings are undesirable in cabinet and furniture woods, as are also glue stains on plywood. To remove these discolorations, chemical bleaches are used. There are a number of proprietary bleaches available and the manufacturers' instructions should be followed. The main source of trouble in using bleaches is that the bleaching chemical is not thoroughly rinsed or sponged off after use, thus ultimately impairing the finish. Spot bleaching should be avoided as much as possible, since it is highly improbable that a uniform surface will result.

2. Staining.—This step in wood finishing requires a great deal of skill and practice. It is always advisable before staining a large piece of work to check the stain on a sample piece of similar wood. Most trouble in staining will be avoided if, when handling stains and thinners, measuring and thorough mixing of the stain is given particular care.

3. Wash-coating.—In order to prevent "bleed-through" of the stain and to seal the raised grain so that sanding will provide a smooth surface, a shellac varnish reduced one part with four or five parts methyl-hydrate is applied. The application of this wash-coat also aids in the prevention of discoloration by keeping out the oils and resins which may be present in the filler and subsequent coatings.

4. Filling.—The filling operation, where necessary in open-pored woods such as oak, walnut, mahogany, and ash, is a most important one. The type of filler to be used is based on method of application, drying time, and desired effect. Fillers may be applied by brush or spray and, after the indicated "setting up" period (usually several minutes), are wiped across the grain, using a felt or cloth pad. The use of a brush for this purpose should be avoided, since the bristles tend to pull the filler out of the pores. A final light wiping with the grain is generally given, to smooth out the coating. Proper drying time is important to prevent lifting by subsequent coatings.

5. Sealing.—Sealers are of two general types, i.e., lacquer sealers and shellac sealers. When applied, the sealer coat should give a uniform continuous film, but should not be heavy enough to cause softening of the filler. A drying period for sealers of up to four hours is necessary prior to sanding. Only a light sanding is necessary, and the dust is best removed by air-blowing or by the use of a tack-rag.

6. Final Coating.—Any glazing or decorating is done before the final coating. The depth of finish, the cost, the lustre desired, and the end use of the article, are all factors governing the choice of finish and the number of coats to be applied. Varnishes, rubbing varnishes, and clear lacquers to suit all uses are readily available.

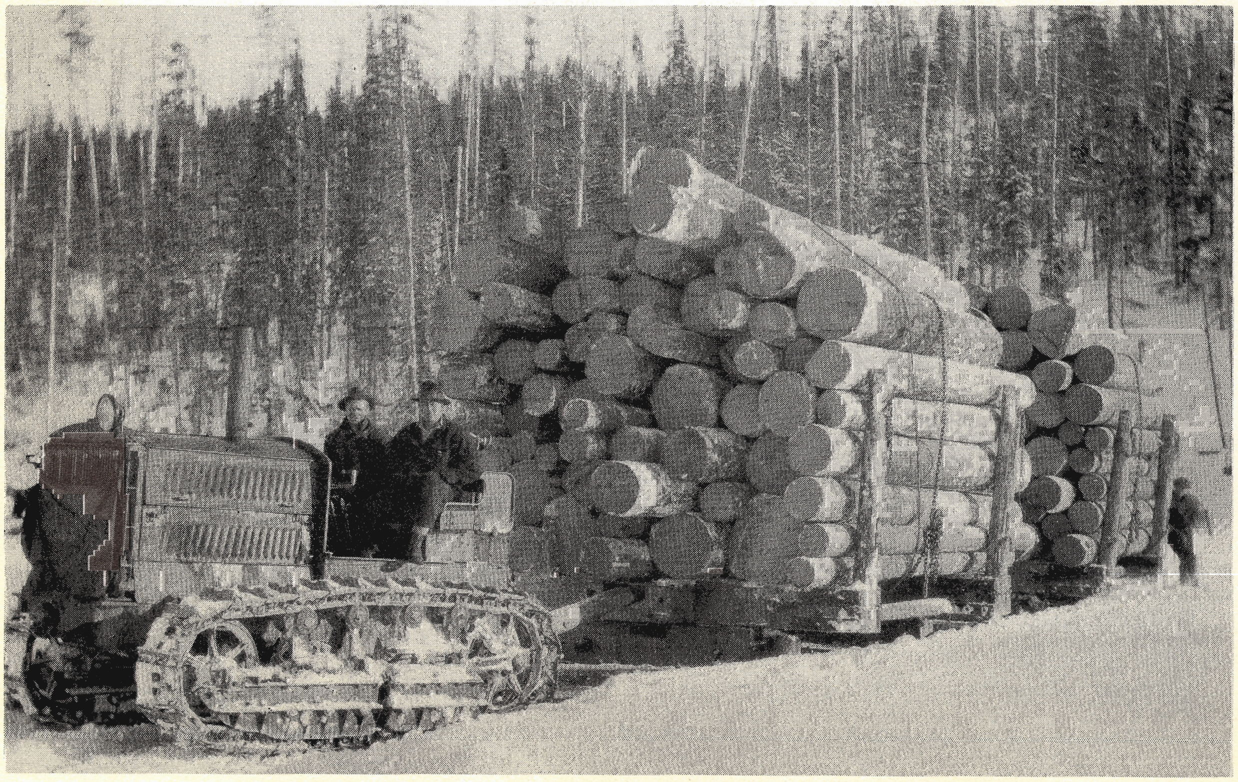
7. Paint or Enamel Finishes.— In finishing new furniture, five steps are usually necessary.

(a) Prepare a smooth, clean surface.
(b) Apply the priming coating.
(c) Apply the enamel undercoating or first paint coat.
(d) Sand the surface smooth, using fine sandpaper, and dust thoroughly.
(e) Apply the final paint or enamel coating.

In re-painting furniture, the following steps are usually required.

(a) Remove all wax, grease and dirt by use of thinner and washing with strong soap solution. Dry thoroughly.
(b) Sand smooth and dust thoroughly.
(c) Apply the paint or enamel coating.

*In using these, manufacturers' directions should be strictly followed.



Log Hauling, Old and New.

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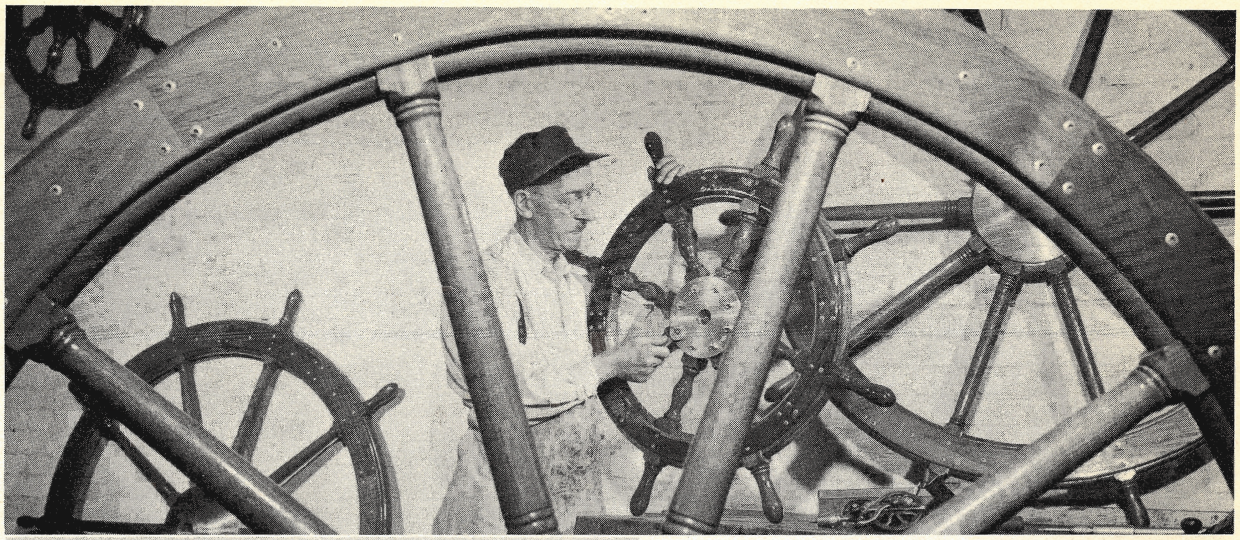
PLATE 84.—Highway Bridge at Haig, B.C,—Concrete surface on creosoted timber deck carried on creosoted timber bents.



WOOD

FOR

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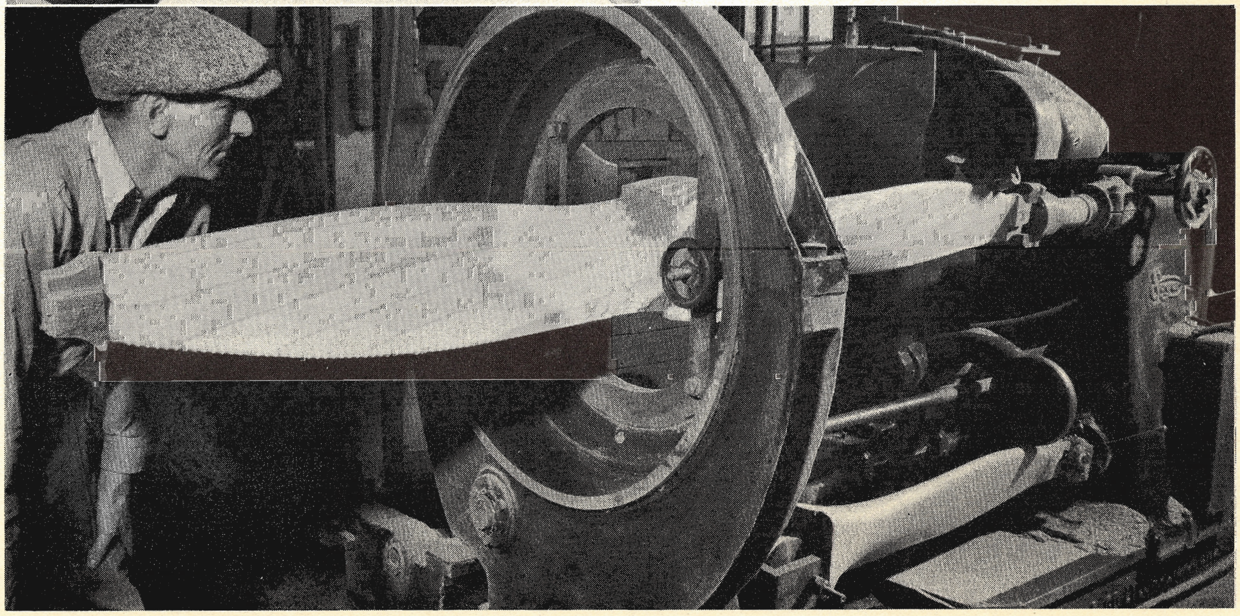
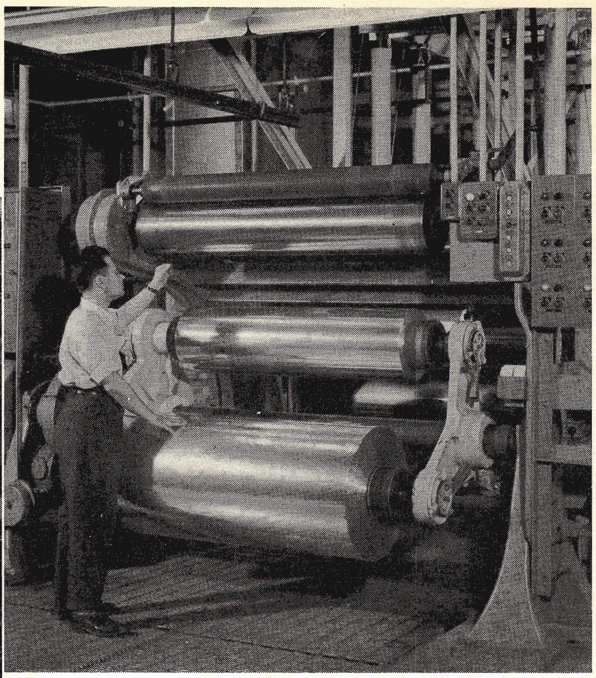
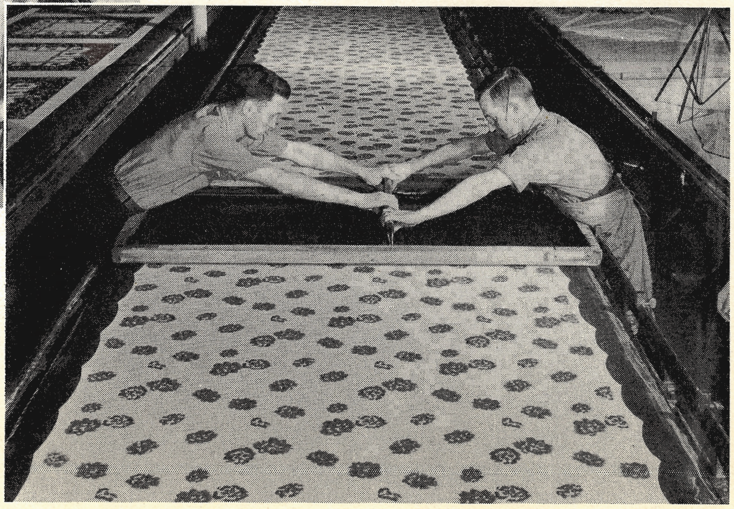


It would be difficult today to imagine life without cellophane.



Spooling Rayon Yarn. This wood product is further invading year by year the fields of cotton, linen, silk, and wool.



Printing the design on rayon fabric by the silk-screen process.

TRANSFORMATIONS OF WOOD

CHAPTER 8

THE CHEMICAL UTILIZATION OF WOOD*

By C. GREAVES and H. SCHWARTZ†

CHEMICAL COMPOSITION

WOOD substance, i.e., the cell membrane or wall, consists of the major elements of plant life, cellulose, hemicellulose, and lignin, the principal one being cellulose. The minor constituents, such as oils, resins, sugars, starches, tannins, dyes, nitrogenous substances, inorganic salts, and organic acids, which function in the life processes of the plant are contained in the cell cavities or in special structures produced by modification of the cells.

Elementary Composition

When wood is subjected to elementary analysis, it is found to be composed of approximately 50 per cent carbon, 6 per cent hydrogen, and 44 per cent oxygen there being very little variation between different species, between the heartwood and the sapwood, or between the various parts of the tree. Analyses, by Gottlieb (12), of various European woods, shown in Table 20, indicate its typical elementary composition.

*In this chapter, only chemical utilization apart from the pulp and paper field is covered; the latter is discussed in Chapter 14.

†In bringing this chapter up to date, extensive use has been made of the original material prepared by Mr. F. G. Marriott and Dr. C. Greaves for the first edition.

Analytical Composition

More detailed methods than elementary analysis have been developed for the approximate determination of the complex aggregates which make up the wood substance, the extractives, and other components. These methods give results such as those shown in Table 21, analyses of woods, by Wise (49); in Table 22, analyses of Douglas fir, western hemlock and western red cedar, by Bray and Martin (3); and in Table 23, analyses of sapwood and heartwood of some American woods, by Ritter and Fleck (37). It may be noted that the principal variation with regard to species is between the hardwoods and the softwoods, the hardwoods having less lignin but more pentosans, methoxyl, and acetyl than the softwoods. While such analytical results are of considerable value in characterizing the various species of wood, they are by no means absolute, and are of value chiefly for comparative purposes. It will be apparent that there is considerable overlapping in the various analyses, in view of the fact that the total percentage in all cases exceeds 100.

In recent years, with the development of improved methods for isolating the carbohydrate components

of wood (22, 45, 47) attempts were made at summative analysis, particularly by Wise and co-workers (47, 48). Two typical summative analyses of black spruce wood reported by Wise and Ratliff (48) appear in Table 24. The difference between the two analyses is that in the second the hemicellulose and so-called α-cellulose fractions are broken down into individual carbohydrate components.

Results of summative analyses for some species are even closer to 100 per cent than those for black spruce, and while this represents a great improvement over older methods of reporting the composition of wood, there still are problems to be solved. An apparently satisfactory summative analysis is sometimes the result of a balancing-out of errors.

TABLE **20**

ELEMENTARY COMPOSITION OF WOOD

Species	Carbon	Hydrogen	Oxygen	Nitrogen	Ash
Beech	49.14	6.16	44.07	0.09	0.54
Birch	48.88	6.06	44.67	0.10	0.29
Pine	50.36	5.92	43.39	0.05	0.28
Spruce	50.31	6.20	43.08	0.04	0.37

TABLE **21**

ANALYSES OF WOODS (Mean Values Obtained by the U.S. Forest Products Laboratory)
Results in percentage of oven-dry (105°C) wood.

Species	Ash	Solubility in				Acetic Acid	Methoxyl	Pentosan	Methylpentosan	Cellulose	Lignin	In Cellulose				
		Cold Water	Hot Water	Ether	1% NaOH							Pentosan	Methylpentosan	Cellulose alpha*	Cellulose beta*	Cellulose gamma*
Western yellow pine (*Pinus ponderosa*)	0.46	4.09	5.05	8.52	20.30	1.09	4.49	7.35	1.62	57.41	26.65	6.82	1.98	62.10	10.56	30.13
Yellow cedar (*Chamaecyparis nootkatensis*)	0.43	2.47	3.11	2.55	13.41	1.59	5.25	7.87	3.42	53.86	31.32	7.30	1.78	62.68	11.06	26.25
Incense cedar (*Libocedrus decurrens*)	0.34	3.64	5.38	4.31	17.69	0.91	6.24	10.65	1.35	41.60	37.68	9.08	1.99	46.92	11.67	41.06
Redwood (heartwood) (*Sequoia sempervirens*) ..	0.21	7.36	9.86	1.07	20.00	1.08	5.21	7.80	2.75	48.45	34.21	7.40	2.09	78.81	2.95	18.24
Western white pine (*Pinus monticola*)	0.20	3.16	4.49	4.26	14.78	1.03	4.56	6.97	3.22	59.71	26.44	5.33	1.95	64.61	16.32	19.06
Longleaf pine (*Pinus palustris*)	0.37	6.20	7.15	6.32	22.36	0.76	5.05	7.46	3.60	58.48		7.71	1.16			
Douglas fir (*Pseudotsuga taxifolia*)	0.38	3.54	6.50	1.02	16.11	1.04	4.95	6.02	4.41	61.47		5.34	1.20			
Western larch (*Larix occidentalis*)	0.23	10.61	12.59	0.81	22.14	0.71	5.03	10.80	2.81	57.80		8.94	1.19			
White spruce (*Picea canadensis*)	0.31	1.12	2.14	1.36	11.57	1.59	5.30	10.39	3.55	61.85		9.63	0.72			
Tanbark oak (*Quercus densiflora*)	0.83	4.10	5.60	0.80	23.96	5.23	5.74	19.59		58.03	24.85	22.82		56.77	19.92	23.03
Mesquite (*Prosopis juliflora*)	0.54	12.62	15.09	2.30	28.52	2.03	5.55	13.96	0.70	45.58	30.47	17.75	0.81	76.48	2.35	21.17
Balsa (*Ochroma lagapus*)	2.12	1.77	2.79	1.23	20.37	5.80	5.68	17.65	0.86	54.15	26.50	19.99	1.35	75.64	0.27	24.08
Hickory (Shellbark) (*Hicoria ovata*)	0.69	4.78	5.57	0.63	19.04	2.51	5.63	18.82	0.80	56.22	23.44	21.89	1.41	76.32	2.82	20.35
Eucalyptus (*Eucalyptus globulus*)	0.24	4.67	6.98	0.56	18.57	1.85	6.73	20.09	2.33	57.62	25.07	20.96	2.46	68.86	0.70	31.10
Basswood (*Tilia americana*)	0.86	2.12	4.07	1.96	23.76	5.79	6.00	19.93	3.73	61.24		24.28	1.54			
Yellow birch (*Betula lutea*)	0.52	2.67	3.97	0.60	19.85	4.30	6.07	24.63	2.69	61.31		28.30	1.16			
Sugar maple (*Acer saccharum*)	0.44	2.65	4.36	0.25	17.64	4.46	7.25	21.71	2.39	60.78		24.48	0.96			

*Words alpha, beta, and gamma do not appear in table by Wise (49).

TABLE 22

PERCENTAGE ANALYSES OF DOUGLAS FIR, WESTERN HEMLOCK, AND WESTERN RED CEDAR
(Oven-dry basis)

SPECIES	CELLULOSE Total	CELLULOSE Alpha	Lignin	PENTOSANS Total	PENTOSANS In Cellulose	SOLUBILITY IN Alcohol-Benzene	SOLUBILITY IN Ethyl Ether	SOLUBILITY IN 1 % NaOH	SOLUBILITY IN Hot Water	Ash
	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.
DOUGLAS FIR *(Pseudotsuga taxifolia)*	57.8	43.8	28.8	6.9	4.9	4.5	1.8	13.7	4.7	0.1
WESTERN HEMLOCK *(Tsuga heterophylla)*	58.2	40.7	31.2	8.1	9.6	3.9	1.3	11.7	4.2	0.4
WESTERN RED CEDAR *(Thuja plicata)*	48.7	38.0	31.8	9.0	6.9	14.1	2.5	21.0	11.0	0.3

TABLE 23

ANALYSES OF SAPWOOD AND HEARTWOOD OF SOME AMERICAN WOODS
Results in percentage of oven-dry (105°C.) weight

SPECIES	SAMPLE NUMBER	MOISTURE	ASH	SOLUBILITY IN: COLD WATER	HOT WATER	ETHER	1 PER CENT NaOH	ACETIC ACID	METHOXYL	PENTOSAN	METHYL PENTOSAN	CELLULOSE	LIGNIN	IN CELLULOSE: PENTOSAN	METHYL PENTOSAN	ALPHA	BETA	GAMMA
WHITE ASH																		
No. 2 sapwood ..	179	5.34	0.61	5.81	6.41	1.17	21.77	3.23	4.70	19.85	2.40	50.38	26.95	18.83	1.60	74.67	13.67	11.66
No. 2 heartwood	180	5.45	0.30	2.24	3.40	0.43	19.59	2.31	5.36	19.90	2.25	53.56	27.39	16.75	1.34	64.68	24.58	10.84
No. 3 sapwood ..	181	4.91	0.57	5.25	7.02	0.88	21.93	3.70	5.66	20.16	2.63	49.72	27.39	19.67	1.60	55.11	28.99	16.50
No. 3 heartwood	182	7.42	0.32	2.12	4.46	0.46	18.97	2.66	5.20	19.87	2.46	53.40	28.38	17.34	1.47	42.45	33.22	24.33
YELLOW BIRCH																		
No. 1 sapwood ..	207	4.92	0.26	1.05	1.98	0.48	16.77	2.34	5.66	21.36	1.66	58.91	24.69	20.72	1.13	52.15	32.90	14.45
No. 1 heartwood	208	4.76	0.40	4.16	5.69	0.81	20.51	1.78	5.46	20.37	1.39	56.88	24.62	21.87	1.12	61.17	23.23	15.60
No. 2 sapwood ..	213	4.28	0.18	1.74	2.10	0.88	19.78	3.75	5.47	22.30	1.82	56.57	27.76	22.19	1.71	52.40	26.82	20.78
No. 2 heartwood	214	4.36	0.23	2.76	3.96	0.99	21.14	2.83	5.27	23.21	1.07	54.93	28.13	21.81	1.04	53.56	25.00	21.44
WHITE PINE																		
No. 1 sapwood ..	193	3.90	0.23	3.55	5.15	5.46	17.16	1.68	4.16	9.31	2.14	54.25	26.51	6.81	2.09	54.56	17.47	27.97
No. 1 heartwood	194	2.92	0.42	5.97	7.68	3.62	19.15	1.43	4.60	8.56	1.00	50.23	26.14	7.12	2.02	57.29	22.42	19.29
WHITE CEDAR																		
No. 3 sapwood ..	199	6.02	0.48	3.02	3.96	1.44	12.71	1.11	5.23	10.82	1.16	55.02	32.14	8.95	1.28	69.17	14.04	16.79
No. 3 heartwood	200	6.48	0.27	2.80	4.01	1.87	14.14	0.74	5.09	10.36	1.56	54.42	32.42	7.97	1.32	55.22	24.74	20.04

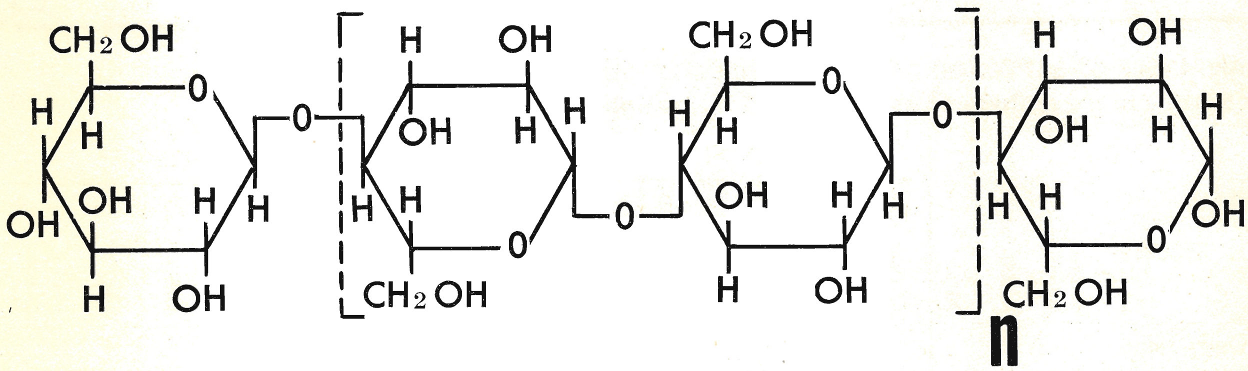
TABLE 24

SUMMATIVE ANALYSIS OF BLACK SPRUCE WOOD (Extractive-free, oven-dry basis)

	ANALYSIS 1	ANALYSIS 2
	per cent	per cent
Ash	0.36	0.36
Acetyl	1.12	1.12
Lignin	28.0	28.0
Hemicellulose	17.4	—
α-Cellulose	51.5	—
Xylan (corrected for uronic anhydride)		10.5
Uronic anhydride		4.1
Mannan		8.0
α-Cellulose (corrected for mannan, xylan, and uronic anhydride)		45.6
CH_2 (calculated from methoxyl not in lignin)		0.22
Total	98.38	97.90

Cellulose

Wood cellulose constitutes more than 50 per cent of the cell wall, and is the basis of the plant structure. It exists in wood associated with other carbohydrate constituents, and it is a very difficult matter to isolate it in a pure and unchanged form. True cellulose is considered to consist of a long chain of *B*-d-glucopyranose units joined in the 1,4 positions, as shown in the following illustration:



The repeating unit consists of two glucopyranose units, known as a cellobiose residue. The length of the cellulose chain will depend on the source and method of isolation of the cellulose. The method of determining the chain length is also an important factor. Mark (32) states that in some samples of native cellulose, the molecules consist of chains with as many as 6,000 to 8,000 glucose residues. In commercial cellulose preparations, average degree of polymerization (average value of 'n') is between 1,500 and 3,500.

Cellulose is more resistant to chemical action than most of the other substances associated with it. Nevertheless, under the action of certain reagents, it is capable of producing a number of substances of great industrial importance, such as: (1) cellulose nitrate, used in explosives, plastics, and lacquers; (2) cellulose acetate, used in artificial silk, motion picture film, plastics, and lacquers; (3) cellulose xanthate, used in the manufacture of viscose silk and cellophane; (4) carboxymethyl-cellulose, used in textile sizing and as an emulsifying agent. There are a large number of cellulose esters and ethers that find a variety of uses, particularly in the plastics industry.

Hemicellulose

The hemicelluloses may be defined as the non-cellulosic polysaccharides of the cell wall. They are, however, more usually defined by the method of isolation from wood. They are usually considered to be the carbohydrate fraction removable from wood by dilute alkali and capable of being hydrolyzed by dilute acids to simple sugars and sugar acids. Two hemicellulose fractions are often differentiated, i.e., the polyuronide fraction, often considered to be associated with the lignin, and the cellulosans, thought to be associated with cellulose. The cellulosans presumably consist of pentosans and hexosans of relatively short chain-length.

The hemicellulose content of hardwoods ranges from about 20 to 28 per cent, while that of softwoods is usually around 15 to 20 per cent. Hardwood hemicelluloses largely contain xylose units with some methylhexuronic acid units, while softwood hemicelluloses contain in addition a considerable portion of mannose units.

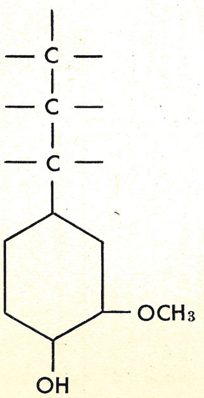
The method of alkali extraction hitherto used for the isolation of hemicelluloses from wood has been inadequate from the point of view of quantitative recovery and purity. In recent years, methods have been developed for the isolation of the total carbohydrate fraction (or holocellulose) in a lignin-free form (22, 45, 47). Holocellulose has proved to be an excellent material from which to recover, almost quantitatively, the hemicellulose fraction in a lignin-free form. This development has provided a better approach to the study of the chemistry of the hemicelluloses.

Lignin

Lignin constitutes about 25 to 30 per cent of the dry weight of softwoods and about 20 to 25 per cent of hardwoods. Ritter (38) has pointed out that lignin is found (a) in the middle lamella, the continuous layer of bonding material between the walls of adjacent cells, and (b) throughout the cell wall. It is claimed (10) that the function of the lignin is to bind or cement together the numerous fibrillae of the layers of the cell wall.

The structure of lignin, although it has been a subject of much chemical research in the past fifty years, is not yet definitely known. The problem of lignin study is complicated by the fact that no method has yet been found to isolate lignin quantitatively and in unchanged state. It is usually obtained as an amorphous material of apparently high molecular weight. Furthermore, its properties vary with the method used for its isolation, with the result that very few, if any, investigators in the field have worked with precisely similar material.

From experiments on alkaline hydrolysis, alkaline oxidation, hydrogenation, and ethanolysis, it has been established that lignin is partly aromatic in structure. Furthermore, it is generally accepted that most, if not all, of the basic units in lignin consist of a benzene ring with a 3-carbon side chain (4), referred to as a C_6-C_3 unit. In softwoods, this unit has the guaiacyl grouping (I) and in hardwoods, units with the guaiacyl and syringyl (II) groupings are present. Lignin in wood is considered to be a polymer containing these C_6-C_3 units, but the exact nature of the C_3 side chain, the linkage between the C_6-C_3 units, and the complexity of the polymer are not known. Any structural formula for lignin that may be written down at this time is largely speculative.



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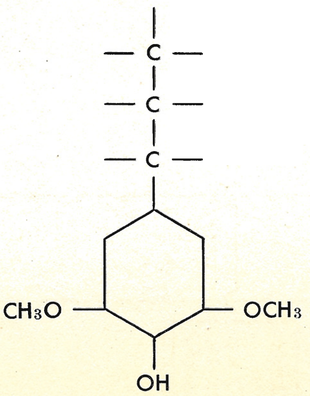

2

Extractives

The substances in wood commonly referred to as extractives are in general those substances which are soluble in neutral solvents, such as alcohol, ether, water, etc. They do not form an integral part of the cell wall and are not necessarily distributed uniformly throughout the tree. Under extractives may be included materials such as fats, fatty acids, phytosterol, resenes, resin acids, waxes, colouring matter, tannins, phlobaphenes, sugars, polysaccharides, salts, acids, aldehydes, alcohols, and hydrocarbons.

The amount of extractives in common Canadian woods is relatively low. For example, the ether-solubility of individual samples of jack pine, red pine, and Douglas fir heartwood was found to be 1.99, 4.12, and 1.14 per cent, respectively (40). While ether-solubility does not include all extractives in wood, it provides some indication of the amount of extractives, exclusive of most water-soluble materials.

The extractives are both actually and potentially of some commercial importance. For example, the resinous components in certain foreign species form the basis for the naval stores industry (see page 220). The volatile oils in wood and leaves of a number of species give rise to the essential oils industry (see page 223). The recovery and commercial use of fats, waxes and resins from the solvents used in solvent seasoning of wood (see page 156) might make this method of seasoning practical. The fatty and resinous components of pines are responsible for the formation of the tall-oil fraction (25) during the pulping of these woods by the sulphate process. The extraction of tannins from the wood, bark, and leaves of many trees has for a long time been a very important industry.

Tannins are astringent materials which have the property of acting on animal skins and converting them into leather. They are defined as that portion of the water-soluble matter of certain vegetable materials which will precipitate gelatin from solution and which will form, with hide powder, compounds which are resistant to washing. Large quantities of these materials are required in the leather industry in many countries.

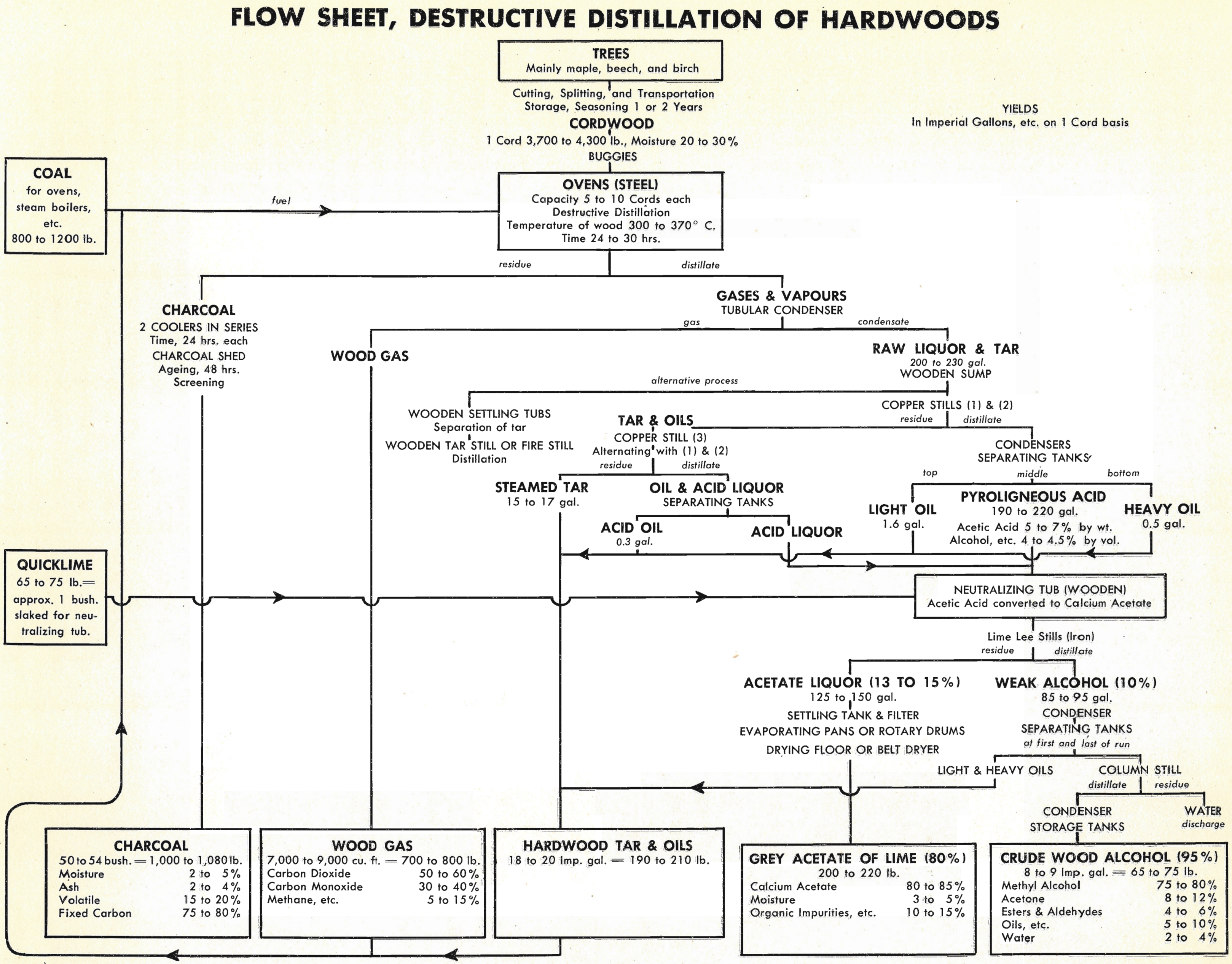

Figure 33.—Flow Sheet Outlining the Process of Wood Distillation and its Products.

Canada imports about 99.5 per cent of its tannin requirements. The chief imports are quebracho from South America, chestnut from the United States, and wattle from South Africa. Such extreme dependence on outside sources is obviously undesirable. Furthermore, in recent years the price for these imported materials has risen so sharply that it is considered most desirable that Canadian sources for tannins should be developed.

A number of Eastern Canadian species contain considerable quantities of tannin. For example, eastern hemlock bark contains 11 per cent tannin, white spruce bark about 20 per cent, and three species of sumac 16 to 24 per cent. Of these materials, hemlock and spruce present the best possibilities for commercial exploitation. There are plentiful supplies of spruce bark at pulp mills, but further information on the quality of the tannin from this bark is required before large-scale utilization can be undertaken. Eastern hemlock bark was once a major source for tannin in Canada. However, supplies of hemlock bark have been decreasing as the accessible stands have been gradually depleted, and today only a few tanneries are leaching hemlock bark for their own use; with the increased cost of imported tannin, it may again become economically possible to do this.

In Western Canada, the barks of western hemlock and second-growth Douglas fir offer possible sources for tannin. Western hemlock bark contains about 15.5 per cent of tannin and is known to be a valuable tanning agent. Contamination of the bark with salt, resulting from the practice of towing logs in sea water prior to barking, is one of the main drawbacks to the development of western hemlock bark as a tannin source*. Changes in present logging practices appear to be necessary before large-scale utilization of western hemlock bark may be achieved. The tannin content of Douglas fir bark varies from the bottom to the top of the tree and also with the age of the tree (29). It has been shown that the tannin content varies from 8 to 18 per cent from the bottom to the top of Douglas fir trees in the 50 to 80 years age class. Satisfactory use of this tannin is reported by one tannery on the Pacific Coast. However, it is considered that further tests are necessary to evaluate fully the properties of Douglas fir bark tannin.

*Methods of removing the salt from the extracted tannin have been studied in the laboratory, and the results seem encouraging enough to justify tests on a commercial scale.

DESTRUCTIVE DISTILLATION

IN DESTRUCTIVE distillation, the wood is heated in retorts, out of contact with the air. In the non-oxidizing atmosphere so produced, the various complex organic components, such as cellulose and lignin, decompose, leaving in the retort a residue of charcoal, and producing considerable quantities of gas, part of which, on cooling, condenses as a liquid from which are derived acetic acid, methyl alcohol, and wood tar: the uncondensable gases are burnt as fuel. The process is sometimes termed 'carbonization', while the industry is known as the 'wood-distillation industry'.

It was about 1830 when the industry first made its appearance in the United States, where large quantities of suitable hardwoods were, and still are, available. It expanded and developed until at the end of World War I, according to Bates (1), U.S. production amounted to about 60 per cent of world production; Canadian output was about 6 to 8 per cent, the remainder being produced by countries in Central Europe. It was not until many years after production was begun in the United States that the industry was established in Canada, where it is largely confined to the Provinces of Ontario and Quebec.

The products of destructive wood distillation, with the exception of charcoal, are not directly marketable, but must undergo further treatment at secondary plants where they are converted to marketable products. During World War I and its post-war period, Canada was able to export considerable quantities of such products. At present, most of the products of wood distillation, except charcoal, can be prepared more cheaply by other methods. The industry has to depend almost solely on its charcoal markets for survival.

The crude distillation plants are invariably located near the source of the raw material, and must have an adequate water supply for use in condensers and for other phases of the process. There should be sufficient wood available for continuous operation. A crude distillation plant in Canada usually has a capacity of from 40 to 110 cords per day. For such plants, from 10 to 40 acres of land are necessary in order to provide sufficient space for drying at least a year's supply of wood, for the necessary tracks leading to ovens, coolers, etc., and for the buildings in which the equipment is housed.

Wood Supply

The species generally employed are the heavier hardwoods; in Canada, maple, beech, and birch are used almost exclusively, elm and ash only occasionally, in the United States, oak is often used. Softwoods are not used*, as the charcoal produced is inferior in quality, and the yields of products per cord are much lower than for heavy hardwoods. Light hardwoods, such as basswood and poplar, are not suitable, as the yields per cord are also low.

Farmers or jobbers are usually employed to cut, split, and haul the wood from the bush to the plants during the winter season. The wood is cut into lengths of 50 to 52 inches, without removing the bark, and all pieces larger than 8 inches in diameter are split to smaller sizes. When the wood is received it is stacked to dry for at least one year. This necessitates having a whole year's supply always on hand, which means tying up considerable capital, thus increasing the cost of production.

The gathering of wood for distillation often accompanies lumber operations, small trees, limbs, etc., that are unsuited for lumber being utilized. It is generally conceded that heartwood gives higher yields than sapwood, and that yields from second growth are lower than from virgin growth; yields from decayed wood are low.

Processes

The various types of apparatus that have progressively led to the development of that in use today are, in the order of their introduction, charcoal kilns (without recovery of by-products), brick kilns, iron or steel retorts, and, lastly, the modern steel ovens. Brief descriptions of the older types, and a more detailed account of the present Canadian type of carbonizing containers and the methods of using them follow.

Charcoal Burning

Well-dried wood is stacked up on the ground in the shape of a beehive, a vertical channel being left at the centre of the stack to produce a draught. The wood is then covered over with leaves and dirt, and a hole is left at the top of the channel with some holes near the bottom to supply the necessary air. By setting the wood on fire and allowing some of it to burn, sufficient heat is supplied to cause the carbonization of the remainder. The method is extremely wasteful, the yield being about 30 to 35 bushels of charcoal per cord. The capacity of the kilns varies from 3 to 50 cords, a convenient size being 5 to 6 cords, taking 2 to 4 days for a complete run.

*Distillation of softwoods is one of the methods used for the preparation of naval stores.

Brick Kilns

Brick kilns are an improvement on the primitive charcoal kilns, and were designed to save the labour involved in building a new kiln for every charge and to recover some of the volatile by-products. Well-seasoned wood is stacked in large brick kilns, beehive in shape, and holding from 20 to 90 cords. Wooden pipes lead from the tops of the kilns to condensers through which the gases given off during the distillation are drawn by means of fans. The heating is effected partly by burning wood, gas, or other fuel under the kilns, and partly by allowing some of the wood in the charge to burn, this being accomplished by controlling the air supply by suitable vents. The chief product is charcoal. Some acetate of lime and methyl alcohol are obtained from the condensate. A complete charge can be run in 15 to 25 days.

Brick kilns where no recovery of by-products is made are also used (15).

Retorts

The first retorts to give high yields of by-products were horizontal cylinders of cast-iron, 8 feet long and 42 inches in diameter, with a capacity of five-eighths of a cord. Later retorts are slightly larger and made of steel. They are usually set in pairs, and charged by hand. A complete run takes from 16 to 24 hours. The retorts are heated by burning, in a firebox underneath, coal, wood, gas, or tar. The gases evolved are led through condensers, and acetic acid, methyl alcohol, and other products are obtained from the condensate. The yield from retorts is slightly less than from ovens. This process is not used in Canada.

Ovens

The standard ovens used in Canada are made of steel, are 6 feet 3 inches wide, 8 feet 4 inches high, 26 to 54 feet long, and hold from 5 to 10 cords of wood. In the best type of oven, there are doors at both ends which can be closed gas-tight, and a wide nozzle, which connects with a vertical copper-coil condenser, riveted to the top or side. The ovens

are set in bricks and are equipped with steel hangers, which are riveted to the sides; by means of these the ovens are hung on T-rails laid across the brick settings, and any trouble due to expansion is thus avoided. The ovens are set with the bottoms at the level of the ground, and are heated at one or both ends by furnaces below the ground-level, so designed that the heat is evenly applied to the bottom and sides of the ovens. The fuel used may be coal, wood, wood gas, tar, or powdered charcoal.

Seasoned wood, 50 inches in length, is stacked cross-wise on flat steel cars, called "buggies", each holding 2 to 2½ cords. The buggies are run on rails leading into the ovens. When a charge is removed from an oven, it can be immediately replaced by another, thus speeding up operation and conserving heat.

During the first 5 or 6 hours of treatment of a new charge, a vigorous fire is applied until the first condensate is noticeable, which occurs at a temperature of 100°C. The temperature is then gradually raised until it is about 270°C., at which temperature decomposition is rapid and considerable heat is evolved, i.e., the reaction becomes exothermic. This necessitates a greatly reduced amount of firing, to prevent excessively high temperatures, which cause low yields of the desired products. As an aid in regulating the temperature, steam is injected into the ovens just before the exothermic reaction begins and also while it is in progress. The carbonization of the wood occurs mainly between the temperatures of 300 and 370°C. Considerable variation in the yields of the various products of distillation can be obtained by varying the temperature conditions under which the carbonization is carried out. Canadian practice aims at a slow rise in temperature to avoid overheating, a charge being completed in from 24 to 30 hours. The progress of the operation is determined by observing the colour and quantity of the condensate and the temperatures registered by thermometers set in the nozzles.

A small amount of acetic acid is present in the first condensate after about 5 hours and, as the heating continues, the percentage of acetic acid gradually increases, reaching a maximum of 12 to 14 per cent after about 15 hours, and then gradually decreasing. Small quantities of light tar first appear after about 5 hours, and the amount of tar continues to increase until the end of the operation.

On page 214 is a copy of a flow sheet compiled by Bates (1), who describes the process as carried out in Canada, and includes estimates for raw materials and yields. The main products obtained are charcoal, raw liquor, and wood gas. Further treatment of these products is described below.

Charcoal.—When the carbonization has been completed in an oven, the buggies containing the charcoal are moved into a cooler, i.e., a container of light construction similar in size and shape to an oven and having doors at both ends. After remaining 24 hours in the closed cooler, the buggies are moved to a second cooler for another 24 hours, after which the charcoal remains in covered sheds for 48 hours to season before being screened. It is then loaded, either in bulk or after being placed in paper bags, on railway freight cars, where it must remain a further 12 hours before shipment. The charcoal is cooled in the absence of air to prevent loss through burning. During the seasoning period, considerable quantities of oxygen are absorbed, and this often results in spontaneous combustion. Hence the regulations as to cooling and seasoning before shipment are very strict.

Raw Liquor, Wood Gas, and Wood Tar.—The condensate from the ovens in the destructive distillation of the wood is called "raw liquor" and consists of a mixture of tar and pyroligneous acid, i.e., an aqueous solution of acetic acid, methyl alcohol, etc. The raw liquor is separated from the uncondensable gases by means of a goose-neck pipe at the bottom of the condenser. The uncondensed gases, known as "wood gas", and consisting mainly of carbon dioxide, carbon monoxide, and paraffin hydrocarbons, pass from the condenser (sometimes first through scrubbers) to be used as fuel. The raw liquor accumulates in a wooden tank, called a "sump", from which it is charged continuously into a copper still, heated by steam coils, and having a capacity of 3,000 to 4,000 gallons, where the aqueous solution is distilled off. When a considerable amount of tar has accumulated in the still, the raw liquor is diverted to another copper still (usually there is a battery of 3 stills), and live steam is blown through the tar to remove the last traces of acetic acid and methyl alcohol. The residue, which is known as "wood tar" is generally used as fuel.

Acetate of Lime and Crude Wood Alcohol.— The condensate from the copper stills mentioned above, after passing to separating tanks, where a further separation of tarry oils is effected, is neutralized in wooden tanks with slaked lime. This converts the acetic acid to acetate of lime, the chemical reaction involved being represented by the equation:

$$2CH_3.COOH + Ca(OH)_2 = Ca(CH_3.COO)_2 + 2H_2O.$$

The resulting solution, after settling and filtering, is then transferred to steel stills, called lime lee stills, which are heated by steam passing through copper coils and are equipped with copper condensers. After distillation, the residue, containing about 15 per cent of acetate of lime, is concentrated in flat, steam-jacketed evaporating pans until there remains a moist mass of acetate crystals. These crystals are spread out to dry on brick or concrete floors built over the ovens, thus utilizing waste heat, and are then ready for shipment as grey acetate of lime.

The distillate from the lime lee stills, which contains about 10 per cent by volume of methyl alcohol, is concentrated by heating in steel alcohol stills equipped with copper steam coils, copper fractionating columns, separators, and condensers. The final product is 94 per cent crude wood alcohol, which is stored in steel tanks and shipped to refineries.

Pre-drying.—In the production of acetate of lime and methyl alcohol, large quantities of water have to be removed, usually by distillation. Hence, it is more economical to use seasoned wood containing 20 to 25 per cent water than green wood containing 60 to 70 per cent. In modern plants, the wood, stacked on buggies, is first placed in closed containers called pre-dryers, similar in shape to ovens, through which the waste gases of combustion pass. The temperature is automatically controlled. Seasoned wood is pre-dried for about 24 hours at 150 to 175°C. before going to the ovens, and green wood can be dried in about 2 or 3 days. By thus utilizing waste heat the products of distillation are obtained in more concentrated form, and a saving in the amount of capital tied up for wood in the seasoning yard is effected.

Concentration of Acetate Solution. —In some modern plants, the Huillard drying process is used. The acetate liquor falls in a thin stream on the outer surface of a revolving drum which is heated internally by steam; the paste thus formed is automatically scraped off and conveyed through a brick chamber, where it is dried by meeting a current of hot gases.

Preparation of Acetic Acid.—Methods have been introduced recently for the production of acetic acid directly. The raw liquor, after the removal of methyl alcohol and tar, is subjected to the action of some solvent for acetic acid which does not mix with water. The solvent is afterwards separated from the water and the acetic acid recovered by distillation. Successfully operating in the United States is the Suida process, in which the aqueous solution of acetic acid is first vaporized and the vapours are then bubbled through the solvent, a high-boiling oil prepared from wood tar.

Another method for direct recovery of acetic acid from pyroligneous liquor involves azeotropic distillation. This process depends on the fact that water forms a constant boiling mixture with a number of compounds, and that the boiling point of this mixture is lower than the boiling point of water alone. For example, if a water–acetic acid–ethyl acetate system is distilled, the water distils off with the ethyl acetate as a constant boiling mixture, leaving practically water-free acid.

Derived Products

Charcoal is the only product marketed without further processing; the other main products—grey acetate of lime and crude methyl alcohol—are the raw materials from which a large variety of marketable products may be derived. The further treatment of these materials is carried out at refineries which are usually situated near the markets. The products are mainly acetic acid, acetone, sodium acetate, methyl acetate, acetic anhydride, methyl alcohol, and formaldehyde.

Acetic Acid

Concentrated sulphuric acid is added to acetate of lime in steam-jacketed, cast-iron stills equipped with "duriron" condensers. When this mixture is heated, a reaction takes place, whereby acetic acid and calcium sulphate are produced according to the equation:

$$H_2SO_4 + Ca(CH_3.COO)_2 = 2CH_3.COOH + CaSO_4.$$

The mixture is kept stirred, and crude acetic acid is collected in the condenser, a slight vacuum being

maintained to assist in the distillation. The residue, consisting of calcium sulphate and various other impurities, is allowed to go to waste. The condensate, containing about 80 per cent acetic acid, must be purified by distillation to remove the impurities, which are chiefly other acids. The concentration of the refined acetic acid is not greater than 80 per cent and, if glacial acetic acid of 99 per cent strength is desired, another distillation from copper stills is necessary.

Acetone

When acetate of lime is heated in closed retorts, decomposition takes place, the acetate of lime being converted to acetone and calcium carbonate according to the equation:

$$Ca(CH_3COO)_2 = CH_3.CO.CH_3 + CaCO_3.$$

In Canadian plants, the acetate of lime is spread to the depth of one inch on trays placed on metal trucks. These trucks are then wheeled into rectangular steel ovens, called Meyer ovens, which are installed in muffle furnaces. The acetone, water, and a considerable amount of impurities are collected in condensers attached to the ovens. The crude acetone must be refined by further distillations and treatment with chemicals. The products obtained are acetone and a mixture of higher ketones known as "ketone oils".

Sodium Acetate

Sodium acetate is prepared by neutralizing weak acetic acid with soda ash and evaporating off the water. The chemical equation representing the reaction is:

$$2CH_3COOH + Na_2CO_3 = 2\ NaCH_3COO + H_2O + CO_2.$$

Sodium acetate can also be prepared directly from the solution of crude calcium acetate obtained in the lime lee stills by the addition of soda ash, which reacts to produce sodium acetate and insoluble calcium carbonate. The calcium carbonate is filtered out and crude sodium acetate solution remains; from this, purified sodium acetate is prepared by evaporation and fractional crystallization.

Methyl Acetate and Acetic Anhydride have been prepared in small quantities in Canada.

Refined Methyl Alcohol

Crude wood alcohol contains, in addition to methyl alcohol, such substances as acetone, methyl acetate, aldehydes, higher alcohols, and water. Purification is effected by treatment with caustic soda and sulphuric acid, followed by fractional distillation. The boiling points of the various constituents are not very close together, but fractional separation by distillation is rendered difficult, as acetone and methyl alcohol yield a constant boiling mixture. Separation is effected in continuous-operation copper stills equipped with purifying, exhausting, and rectifying columns, dephlegmators, condensers, etc. Several grades of methyl alcohol containing small quantities of acetone, and various acetone-alcohol mixtures are the final products.

Formaldehyde

This is prepared by passing vapours of methyl alcohol, along with a carefully regulated amount of air, through a series of heated tubes containing copper gauze, which acts as a catalyst. The hot gases pass on to condensers and scrubbers, where the various products are condensed and separated, the products being commercial formaldehyde and recovered methyl alcohol.

Uses of Products

Charcoal is used chiefly as a household fuel and in the manufacture of charcoal pig-iron; it is also used for other metallurgical purposes, in making certain chemicals (carbon bisulphide, carbon tetrachloride, etc.), black powder, and poultry feed, in purification of water, and for other purposes. Charcoal iron now has to compete with coke iron, which is cheaper and equally satisfactory for all but a few purposes.

Acetic Acid is a widely used material, the largest uses being in the manufacture of lacquers, acetate rayon, white lead, chemicals, drugs, in dyeing processes, and in the manufacture of certain plastics.

Methyl Alcohol is used chiefly as anti-freeze in automobile radiators, as a component for denatured alcohol, and as a solvent for paints, varnishes, etc.

To a limited extent, in some European countries, methyl alcohol is mixed with gasoline for use in internal-combustion engines, but, generally, the price of gasoline is so low as to make this practice of only limited economic importance.

Future Prospects

While World War I was in progress, there was a great demand for the products of the wood distillation industry, especially methyl alcohol, acetic acid, acetone, and formaldehyde, and production was greatly stimulated: methods were then evolved for the production of acetic acid and acetone from other sources, and a few years later in Europe a method was discovered for the synthesizing of methyl alcohol from carbon monoxide and hydrogen. The only remaining product of the wood distillation industry that cannot be produced from other sources is charcoal. Hence the future of the industry depends largely on the extension and development of markets for charcoal.

OLEORESINS

THE term "oleoresin" is applied to a large group of products, the essential constituents of which are resin and volatile oil. These substances are, for the most part, the oleoresinous exudations of plants, and may occur normally or as the result of injury. A few such exudations are produced in Canada by native coniferous trees. These materials will be discussed in the ensuing paragraphs.

Naval Stores

The chief products of the naval stores industry are now turpentine and rosin, whereas originally they were wood tar and pitch, which were largely used in connection with the construction of wooden sailing vessels; hence, the name "naval stores". The United States is by far the largest producer of naval stores, followed by France, Spain, and Portugal in the order given.

Naval stores are produced either from living trees by the process known as turpentine orcharding, or from "lightwood"—so called because it was widely used to make torches for lighting purposes—which consists of the stumps and other waste material remaining from cut-over forests, selected for its high resin content (15 to 40 per cent).

Turpentine Orcharding

The species usually employed in the United States are longleaf pine (*Pinus palustris*) and slash pine (*Pinus caribaea*); and, in France, maritime pine (*Pinus maritima*). Several other pines are used in other countries, but in limited quantities.

The usual procedure is to tap the trees by making, with a sharp instrument, cuts through the bark extending into the sapwood to a depth of at least half an inch, the gum that exudes being caught in boxes* (cavities cut in the tree near the bottom) or in cups attached to the tree by nails and placed below the cuts. Fresh cuts are made once every week from March to October or November; sometimes two cuts per week are made in warm weather. Treatment of cuts with sulphuric acid or caustic soda is claimed (6) to increase the yield of oleoresin very considerably. About seven times a season the contents of the cups are transferred to barrels, which are conveyed to a centrally located still. At the end of each season the gum which sticks to the tree is also collected. This is known as "scrape" and is of inferior quality to that collected in the cups.

The still usually consists of a copper retort, holding from 15 to 20 barrels of gum and connected to a suitable condenser. The crude gum is charged into the top of the still and some water is added; this enables the separation of the turpentine to be carried out at a lower temperature, and thus produces a distillate of higher quality. On heating by a fire under the retort, the turpentine and water pass over, and are condensed and collected in a receiver; the turpentine does not mix with the water and is easily separated and stored in 50-gallon barrels. The rosin which remains in the still is skimmed to remove chips of wood and, after passing through screens and filters, is transferred to barrels where it solidifies on cooling. A barrel of rosin is 500 pounds gross weight (450 pounds net).

About 15 to 20 years ago, naval stores in the United States were obtained largely by turpentine orcharding, only a small amount being prepared from lightwood by the steam-and-solvent process. Today there is more wood† rosin prepared than gum† rosin and a large proportion of the turpentine produced is wood turpentine (5). American practice has been to tap the trees for a maximum of 5 to 6 years (30) before cutting them for lumber. In France the pine forests are specially cultivated and the trees are tapped for from 30 to 50 years (30),

*Present practice is to use cups only, as it has been shown by Dr. Herty, of the U.S. Forest Service, that this is far more economical.

†It is usual to add the prefixes "wood" and "gum" to the names of the products derived from lightwood and from turpentine orcharding respectively; thus we have "wood rosin" and "gum rosin", etc.

after which they are cut for lumber, the cut timber being replaced by new growth; thus the industry is on a stable basis. American practice was formerly neglectful of the future, but during the last 50 years the tendency to crop, rather than consume, forests has been growing.

Several methods have been proposed for the preparation of naval stores from lightwood, but only two have met with any degree of success. These methods are briefly as follows:

Destructive Distillation

Lightwood is placed in rectangular steel retorts equipped with gas-tight doors. The capacity of the retorts varies from 2 to 3 cords (in which case they are charged by hand) to 10 to 20 cords; in the latter the charging is accomplished by running truck-loads into the retorts. Heat is applied either to the sides (in which case a little rosin and tar can be drawn off from the bottom) or to the bottoms of the retorts, which are connected with water-cooled condensers. For the first 12 hours the temperature is not allowed to rise above 450°F., the condensate being light oils and water containing small amounts of acetic acid. During the next 10 hours, while the temperature is maintained at between 700 and 800°F. for the actual destructive distillation, the condensate consists of heavy oils of a tarry nature. Considerable quantities of uncondensable gases are also produced, and used as fuel. Remaining in the retort at the end of the run is charcoal. By fractional distillation, the light and heavy oils are separated. The products that can be obtained include wood naphtha, wood turpentine, pine oil, tar oil, pine tar, and charcoal.

Pine tar is used in the manufacture of tires from natural rubber. During the war years, when imported pine tar was in short supply, it was shown (40) that a Canadian substitute in sufficient volume and of satisfactory quality could be obtained in reasonably good yield by the destructive distillation of selected resinous Douglas fir or white pine mill waste.

Steam-and-solvent Process

Lightwood is reduced to small chips which are charged into steel extractors, of which there is usually a battery, each holding 13 to 15 tons. The chips are steamed, and the vapours pass out through the top of the extractor to water-cooled condensers. The condensate consists of oil and water, which are easily separated. From the oil, by fractional distillation, turpentine and some pine oil are obtained. A hot rosin solvent, usually a low-boiling petroleum fraction, is then run into the extractor. The solvent, containing some rosin in solution, is then transferred to another extractor and used over again to extract another load of steamed chips. This process is repeated until the solvent is saturated with rosin; the solvent and rosin are then separated by distillation. The chips, after the final extraction, are again subjected to steam distillation, to recover any remaining solvent.

In a recent modification of the process, the initial steaming is omitted, the turpentine, pine oil, and rosin being extracted from the wood by a suitable volatile solvent. Solvent, turpentine, intermediate terpene fractions, and pine oil are separated by fractional distillation, leaving as residue crude wood rosin. This is often referred to as the solvent process.

Prospects of Canadian Production

No naval stores have yet been produced in Canada on a commercial scale. However, tests (2) carried out in the United States on ponderosa pine (*Pinus ponderosa*), by tapping in the usual way, indicate yields nearly as great as from longleaf pine. Considerable quantities of ponderosa pine are available in British Columbia, but it must be remembered that the yields obtained by tapping depend on temperature conditions, and that lower yields than in the warmer climate of the Southern United States are therefore to be expected in Canada. It has also been shown (20) that the resin content of ponderosa pine is 8.5 per cent, which is higher than that of longleaf pine. Consideration might be given to the possibility of producing naval stores from selected waste wood of this species if the selected waste had a resin content equal to that in lightwood from the Southern States (15 to 40 per cent resin). It has also been suggested (16, 40) that naval stores might be obtained from selected stumpwood of red pine (*Pinus resinosa*), which is available in Eastern Canada in considerable quantities.

It would seem that the only possibility of producing naval stores in Canada in the near future is from the wood waste of lumber mills. In that case the industry would have to compete with production from lightwood in the United States, where one of the largest items of expense is the cost of collecting material from cut-over forests. By using selected mill waste, high in resin content, and sufficiently low in

price, it may eventually be found economically possible to produce naval stores by the steam-and-solvent process.

Canada Balsam

Canada balsam, or Canada turpentine, is the turpentine-like oleoresin of the balsam fir (*Abies balsamea*), a coniferous tree indigenous to Canada and the United States. It occurs in canals formed by the separation of the cells in the bark of the tree, and collects in small swellings which appear as prominent blisters on the smooth, thin bark of young trees and branches.

The balsam is obtained by puncturing and draining the blisters. It consists of about 24 per cent of volatile oil, the remainder being a hard yellow resin. When first run, it is a transparent liquid of the colour and consistency of honey, but when exposed to the air it gradually loses the volatile oil and dries to a transparent resinous mass. It has an agreeably aromatic odour and a bitter taste.

Canada balsam is used for cementing lenses in optical systems, for mounting microscopic specimens, as a cement for glass, in the manufacture of spirit varnish, and as an antiseptic dressing for cuts and wounds.

Spruce Gum

Spruce gum is an oleoresinous exudation obtained from red, black, and white spruce, all of which are found in Canada and the United States. The oleoresin occurs in ducts in the sapwood, and exudes from the tree as a result of injuries of various kinds. The flow appears to commence in the spring and to be stimulated by hot weather. Fresh exudations of gum gradually harden with cold weather, but remain white and sticky for a year. They then turn darker in colour, but are not of good quality unless allowed to remain on the tree for at least three years.

The collection of the resin or gum can be carried on throughout the year, but conditions are most suitable in the late autumn or winter, when the gum can be readily chipped from the trees.

The oleoresin consists of a volatile oil, several resins, and a gummy substance. For market purposes, two chief grades of gum are recognized, namely, lump and chip. The lump gum is used as gathered, and the chip is cleaned by steaming and straining. Spruce gum is used in medicinal preparations and as a chewing gum.

It has been suggested that turpentine oil and resin might be produced from this oleoresin, but this is not considered commercially feasible, either by tapping the tree or by collecting the gum, inasmuch as the possible yield from spruce is much lower than that obtainable from southern yellow pines, certain of the pines native to Canada, or Douglas fir.

Douglas Fir Oleoresin

Douglas fir oleoresin, also known as Oregon fir balsam or Douglas fir turpentine, occurs in resin ducts throughout the wood. It flows freely from freshly cut sapwood, and also collects in cavities or pockets produced in the tree by wind-shake or other agency.

The oleoresin may be obtained in two ways. First, it exudes from some trees when they are felled, and is allowed to drain into suitable receptacles; secondly, trees are selected which are likely to contain resin pockets, and these are tapped by boring and the oleoresin drained off. When the flow slackens, the holes are blocked and may be drained again in several months.

Experienced collectors appear to have fair success in locating trees containing pockets, though there is little external evidence of their location. The presence of oleoresin in the tree is also determined by an examination of the chips cut from it. Pockets have been found from 2 to 28 inches from the bark.

It has been suggested that the European method of obtaining Venice or larch turpentine could be applied profitably in securing Douglas fir oleoresin. This procedure is to bore holes about 1½ inches in diameter to the centre of the tree in the spring, close them with a wooden plug, and empty them in the autumn.

The oleoresin of Douglas fir is a transparent, syrupy liquid with a pleasant aromatic odour and a bitter taste. It has a pale, greenish-yellow colour, and consists of a volatile oil and a resin. It is used in the manufacture of varnish and porous plasters, in the ceramics industry, and as a substitute for Venice turpentine and Canada balsam. It can be quite readily distinguished from the latter; its lower refractive index makes it less suitable for optical work. As far as is known, little or no Douglas fir oleoresin is gathered in Canada at present.

ESSENTIAL OILS

VOLATILE oils, usually called essential oils, can be obtained from most trees by distillation with steam. These oils can be prepared either from the wood (compare the preparation of naval stores by the steam-distillation and solvent processes) or from the leaves and twigs. Usually the oil derived from the wood is quite distinct in properties from that derived from the leaves of the same species.

The most important of the essential oils produced from trees that occur in Canada are cedar-leaf oil, spruce oil, hemlock oil, pine-needle oil, cedar-wood oil, and birch oil. Leaf oils are produced chiefly in Europe, and there are no records or statistics of the production of any of these oils in Canada, but it is known that small quantities of leaf oils are produced in certain parts of the Provinces of Quebec and Ontario. Production in the United States is not very large and is carried out mostly in the New England States.

Leaf Oils

Leaves and twigs are gathered and passed through a cutting machine, which reduces them to pieces of one-half to one inch in length. The material is then charged into a large vessel which has a steam inlet at the bottom and an outlet at the top leading to a water-cooled condenser. Separation of the oils is easily effected, as they float on the surface of the condensed water. The steam may be obtained from an outside source, or may be generated in the vessel itself. In the latter event the vessel is heated by a fire underneath it, some water is placed in the bottom, and above the surface of the water there is a perforated removable false bottom which rests on lugs and supports the charge of leaves and twigs. The vessel possesses a clamped cover, which enables the charging and discharging of the leaves and twigs to be carried out quickly.

The condenser often consists of a pipe 8 or 10 feet long passing through running water. At the temperature of the steam, some of the oil in the leaves and twigs is converted to vapour and is carried over with the steam to the condenser, where both steam and oil are condensed, the oil collecting to form a separate layer on top of the water; the latter, which contains some dissolved oils, is often returned to the boiler to be used again in making steam; thus the amount of oil lost is kept to a minimum.

In many cases, the steam is generated in a separate boiler, and then led into the bottom of the still at atmospheric or higher pressures and the still is steam-jacketed in order to speed up the distillation by lessening the amount of condensation of steam within the still.

Cedar-leaf Oil

True cedar-leaf oil is produced from red juniper (*Juniperus virginiana*). In the United States, commercial cedar-leaf oil is prepared mostly by New England farmers from the leaves and twigs of red juniper and white cedar, the white cedar contributing by far the greater portion. A leaf oil similar to commercial cedar-leaf oil has also been prepared in the United States from western red cedar (*Thuja plicata*), but, so far as is known, not on a commercial scale. Small quantities of cedar-leaf oil are produced from white cedar in eastern Ontario and certain parts of Quebec.

Production is carried out in the United States during slack periods in winter. The method of preparation is very primitive, the vessel in which the distillation is carried out being usually a wooden box with an iron bottom set on a rock furnace.

The yields obtainable, calculated on the weight of the green leaves, are given by Greaves (13) as: red juniper (*Juniperus virginiana*) 0.2 per cent, eastern white cedar (*Thuja occidentalis*) 0.5 to 1.0 per cent, and western red cedar (*Thuja plicata*) 1.0 per cent. In a recent publication by Risi and Brûlé (36) on the preparation of leaf oils from some conifers of the Province of Quebec, the average of the yields reported for eastern white cedar is 0.45 per cent.

Cedar-leaf oil is used in medicinal preparations, insecticides, floor-dressings, furniture polishes, veterinary soap, liqueurs, perfumes, microscopic work, and as an ingredient of greases and shoe-blacking.

Spruce and Hemlock Oils

These oils are prepared from the needles and twigs of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and hemlock (*Tsuga canadensis*), the yields being, according to Schorger (39), 0.60, 0.10, and 0.40 per cent respectively, on the green weight basis. The average of yields reported by Risi and Brûlé (36) are 0.34 and 0.22 per cent for black spruce and hemlock respectively. Production in the United States is confined to the New England States and is carried out by the farmers in the winter periods when

work is slack. No attempt is made to separate the leaves and twigs according to species, and the resulting oil is a mixture. The oil is obtained by steam distillation, in the same manner as cedar-leaf oil. These oils are used in greases and shoe-blacking, and in liniments and other medicinal preparations.

Pine-needle Oil

Supplies of pine-needle oil have been produced mainly in Europe, especially in Sweden, Germany, and Austria, the species chiefly used being *Pinus sylvestris* and *Pinus pumilio*. There has been intermittent production in the United States and Canada. Schorger (39) conducted a series of investigations on the production of oil from various conifers occurring in the United States, and found that the yields for longleaf pine (*Pinus palustris*) and slash pine (*Pinus caribaea*) of 0.4 and 0.27 per cent respectively, calculated on the weight of the green leaves, compared favourably with the yields from European species.

In Europe, the gathering of the needles and twigs of the pines generally accompanies logging operations, thus utilizing a waste product. The leaves and twigs are placed in sacks and conveyed to the stills, which are usually cylindrical wooden tanks fitted with false bottoms and connected with water-cooled condensers. Distillation is effected by steam in the usual manner. The main product is pine-needle oil, which distils over with the steam, and which has the characteristic aroma of pine needles. Collecting in the bottom of the wooden tank is a non-volatile material which, after being refined, is known as "extract of pine needles". The residue of spent needles, after further treatment, can be used to stuff mattresses, or can be converted by treatment with caustic soda into "pine wool", which is capable of being felted. Where the latter use is planned, the needles must not be cut up before going into the still.

Pine-needle oil is used in the treatment of bronchial and pulmonary troubles, in liniments, as a deodorant in hospitals and sick rooms, and to perfume soaps and bath-waters. It is often adulterated by the addition of turpentine.

Wood Oils

These oils are usually prepared from wood waste selected at sawmills. The wood, if not in the form of sawdust, is reduced to fine chips before the distillation is carried out. Subsequent procedure is exactly the same as for the leaf oils.

Cedar-wood Oils

Considerable quantities of cedar-wood oil are prepared in the United States from the sawmill waste of red juniper (*Juniperus virginiana*). The waste material consists of white sapwood and red heartwood, the latter containing most of the oil. The yield of oil varies from 1 to 3 per cent, depending on the proportion of heartwood in the waste. Production is mostly in Virginia, North Carolina, and Tennessee. The oil is used in microscopic work, polishes, insect destroyers, perfumes, and for scenting soaps.

Birch Oil

This is prepared from the bark of sweet birch (*Betula lenta*) and is almost indistinguishable from oil of wintergreen, which is obtained from the leaves of a small creeping plant (*Gaultheria procumbens*), but is not produced in Canada. Birch oil contains from 98 to 99 per cent of methyl salicylate, which can also be prepared synthetically. Most of the natural oil marketed in the United States is produced in Connecticut and Tennessee.

The bark is reduced to chips and charged into stills, where it soaks in warm water (120°F.) for 12 to 14 hours before being distilled. The oil is not actually present in the bark as methyl salicylate, but this substance is produced by enzymic action during the soaking in warm water. About five pounds of oil are produced from one ton of bark.

Production of Essential Oils in Canada

Considerable quantities of coniferous wood are cut annually in Canada, rendering available large amounts of waste materials, which frequently constitute a serious fire hazard and from which, if economic conditions were advantageous, considerable quantities of essential oils could be prepared. However, at the present time, production in Canada is very small.

MAPLE SAP

THE sap of all the native species of maple contains sugar, but only the sugar maple (*Acer saccharum*) produces sap with a sugar content high

enough to enable syrup and sugar to be profitably extracted.

The sap is composed largely of water, together with about 3 per cent of sucrose, various minor bases such as lime, potash, iron, magnesia, a number of organic acids (the principal one being malic acid), and a small percentage of nitrogenous matter.

The sap flows in the early spring, when changes in temperature cause expansion and contraction in the cells and intercellular spaces of the wood, resulting in alternate pressure and suction. The exact time of flow depends on the weather and the latitude, and the run usually lasts several weeks. The flow of sap is directly in proportion to the leaf area of the tree, and the amount of light the leaves received. The trees must, therefore, be grown under the best conditions in order to ensure optimum production.

Maple Syrup

The approved modern procedure for making maple syrup is by concentrating the sap in shallow evaporating pans, which are heated by a wood fire. The sap is conducted from the storage tank to the evaporator through an automatic regulator, so that the most rapid evaporation possible is secured without danger of burning. When the sap is heated to the boiling point, the nitrogenous matter, etc., coagulates to form a scum, which comes to the surface and is skimmed off with a perforated metal skimmer. As the liquid becomes syrupy it turns an amber colour, and the mineral matter is deposited on the bottom or sides of the pan as "sugar sand". This precipitate is composed largely of calcium malate or malate of lime.

When the syrup has reached the proper density (determined with a hydrometer or from the boiling point), it is filtered through felt or flannel strainers into the cooling vessels. Sometimes milk, white of egg, or other substances, are used as clarifying agents, but their use is not considered essential and they are apt to affect the flavour of the syrup.

The nature of the flavouring substance of maple syrup was investigated by Nelson (33). He concluded that it depends to a great extent on an unstable phenolic substance and a crystalline aldehyde, similar in odour and properties to vanillin.

Maple Sugar

Maple sugar is produced by concentrating the syrup to a higher degree. The clear syrup from the filter is poured into the "sugaring off" pan, which is placed on an arch or stove and boiled until it reaches a proper state of granulation. This point is determined by use of a thermometer or by testing the liquid in cold water, on packed snow, or on ice; when the desired point is reached, the hot syrup is removed from the fire and poured into moulds.

By-products of Maple Sugar

High-grade vinegar may be made from the sugar contained in the wash-water from pans, strainers, and other appliances, together with the "buddy" sap*, which is not suitable for making syrup. The sugar solution is collected in a barrel; some yeast is added, and alcoholic fermentation allowed to take place. The liquid is strained into another barrel, mother of vinegar is added, and the acetic acid fermentation takes place, converting the alcohol into vinegar.

The sugar sand which is collected from the evaporating pans, strainers, and other vessels, is washed with hot water to free it from sugar, and may then be utilized as a source of calcium bimalate, which is considered to be a suitable acid constituent for baking powder. The sugar sand may also be used as a source of malic acid.

SACCHARIFICATION OF WOOD

CELLULOSE and other polysaccharides may be converted into simple sugars by treatment with mineral acids under suitable conditions of temperature and acid concentration. This process is called hydrolysis or saccharification, and its application to the commercial production of sugar solutions from wood or wood waste has met with success in a number of countries, particularly in Germany.

The two main processes in commercial operation in Germany prior to and during World War II were the Scholler and the Bergius. The general details of the Scholler process for the saccharification of wood are as follows. Batches of dilute sulphuric acid of 1.2 to 0.4 per cent concentration are allowed to percolate through wood in a digester at a temperature varying from about 135°C. at the start of a run to about 190°C. at the end. The temperature is controlled by varying the steam pressure. After each batch of acid is added, sugar solution is drawn off from the bottom of the digester, and the wood in the

*The sap that is collected late in the maple syrup season when the buds begin to burst.

digester is then steamed prior to addition of another batch of acid. In the United States during the war years, a number of improvements were made to the Scholler process (17). This process was changed from batch acid-addition to continuous acid-addition, and to continuous drawing off of sugar solution. In this way, the time required for hydrolysis was reduced from 12 to 16 hours to 3 hours. Sugars are obtained in solution in a concentration of 4 to 5 per cent and in a yield of 50 to 60 per cent of the dry weight of the wood. By fermenting the sugars obtained from one ton of dry wood, there can be produced about 42 to 50 gallons of ethyl alcohol.

The Bergius process uses concentrated hydrochloric acid at room temperature to hydrolyze wood. The yield and purity of sugar obtained is higher than in the Scholler process but, because of the very expensive acid-resistant equipment necessary, the process did not gain very wide favour, and will not be described in detail here.

The importance of wood hydrolysis during World War II was in the preparation of alcohol from the sugars obtained. A commercial plant to process wood by an improved Scholler process was erected in the United States, but this plant is unfortunately not in operation at the present time, owing largely to changes in the demand for alcohol and economic conditions in the post-war period. Wood sugars can, of course, be used for purposes other than for alcohol production. For example, in Germany a considerable volume of wood sugar was diverted to food yeast production. In the United States, research is being carried out on the concentration of wood sugars to molasses (18) and the feeding of the molasses to animals. This approach to wood sugar utilization is so far providing favourable results, and may lead to the re-introduction of hydrolysis of wood waste on a commercial scale on this continent.

MISCELLANEOUS PRODUCTS

Galactose and Mucic Acid

THE wood of western larch contains a notable amount of the polysaccharide arabo-galactan. The galactan component may be converted into the hexose sugar galactose by treatment with hot water and dilute acids. On oxidation of the sugar solution with nitric acid, mucic acid is formed and is precipitated when the solution is cooled. Mucic acid has been used in place of tartaric acid in baking powders and self-raising flour, in accelerating the growth of yeast, in plastics, in soft drinks, and in ice-cream acidulants.

Oxalic Acid

Oxalic acid is a technically important substance used in dyeing and printing, in inks, as a bleach for straw and leather, and as a stain remover. It used to be made by alkali fusion of sawdust at high temperatures. It can be obtained from spruce wood in about 65 per cent yield (21), and originates largely from the cellulose in the wood. The commercial production of oxalic acid by alkali fusion of sawdust has been replaced by other methods. In one, carbon monoxide is passed through a mixture of hot sodium hydroxide and coke, forming sodium formate, which between 350 and 400°C. is converted into sodium oxalate and hydrogen. The sodium oxalate is subsequently used to produce oxalic acid.

Potash

The production of potash from wood ashes is a very old process, but one which has not been operated recently except under very special conditions, since the discovery of rich and abundant deposits of potash salts in various parts of the world. The process consists of burning the wood, leaching the ash with water, and evaporating the solution to dryness. It appears that potash from wood ashes cannot be made profitably at the present time, even in a carefully designed plant using waste wood.

Vanillin

By the action of alkali in the presence of nitrobenzene, vanillin is obtained from spruce wood (11) in about 25 per cent yield, based on the weight of lignin. When lignin-sulphonic acid from waste sulphite liquor is treated with alkali in the absence of nitrobenzene, vanillin is obtained in 6 to 7 per cent yield (44). This chemical is being produced commercially in Canada from lignin-sulphonic acid. However, because of the relatively small tonnage of vanillin used, this outlet for lignin is not very great.

THE CHEMICAL COMPOSITION OF BARK

BARK constitutes about 9 to 14 per cent of the log volume (35) for many species, and as such represents a considerable part of the tree. In recent years, pulp-mills and sawmills have shown more in-

terest in the possibility of utilizing bark. Efforts to utilize this material, at present largely waste, are made more difficult by the fact that insufficient knowledge is available as to its chemistry. Barks from different species may vary greatly in composition. Variation in properties of bark may also occur for different trees of the same species. In Table 25 are given analyses, by Clermont and Schwartz (8), of bark from several important Canadian species, i.e., balsam fir, white spruce, black spruce, eastern hemlock, Douglas fir, and western red cedar. The analytical methods used were the usual methods applied to wood and these, it might be mentioned, are not entirely satisfactory when applied to bark.

The main groups of constituents in bark are (1) extractives, (2) lignin and cork material, and (3) carbohydrates. Compared with wood, bark contains materially more extractives and so-called lignin, but considerably less carbohydrates. Two excellent reviews of the chemistry of bark have appeared recently, one by Kurth (28), and a second by Segall and Purves (41). These reviews make it abundantly clear that the present knowledge of the chemistry of bark is very incomplete.

During the last few years, some fundamental research work on the extractives in bark from Cana-

TABLE 25

ANALYSES OF BARK FROM SIX CANADIAN SPECIES (Oven-dry basis)

	BALSAM	BLACK SPRUCE	WHITE SPRUCE	DOUGLAS FIR		EASTERN HEMLOCK		WESTERN RED CEDAR	
				Inner	Outer	Inner	Outer	Inner	Outer
	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.	P.C.
Cold-water-soluble	22.6	25.9	33.9	10.3	20.0	22.7	21.8	2.3	1.0
Hot-water-soluble	26.7	32.3	41.8	13.5	29.2	28.9	30.0	5.3	6.4
Ether-soluble	23.6	25.5	22.9	15.7	34.4	17.5	23.9	4.9	6.3
Ash	2.0	2.4	3.1	2.7	0.9	1.5	1.0	2.8	0.9
Successive extractions with alcohol-benzene, alcohol, and hot water	36.2	38.7	47.7	16.6	42.9	34.1	40.2	9.3	11.5
"Lignin" insoluble in 72 per cent sulphuric acid*	32.3	27.4	27.3	41.5	55.5	38.9	52.7	34.3	41.5
Ash in "lignin"	0.2	0.5	1.0	0.3	trace	0.4	trace	—	—
Soluble in 1 per cent sodium hydroxide*	35.3	39.2	44.0	29.2	44.5	24.1	32.7	20.1	33.6
Pentosans*	12.5	17.4	18.3	9.5	7.4	10.7	8.4	10.9	10.3

*Analyses for "lignin", one per cent sodium hydroxide soluble, and pentosans were carried out on material which had been extracted successively with alcohol-benzene, alcohol and hot water. Yields for these three analyses are based on moisture-free extracted bark.

TABLE 26

ANALYSES FOR REDUCING AND FERMENTABLE SUGARS IN BARK (Oven-dry basis)

	BALSAM	BLACK SPRUCE	WHITE SPRUCE	EAST. HEMLOCK OUTER BARK	DOUGLAS FIR OUTER BARK
	P.C.	P.C.	P.C.	P.C.	P.C.
Reducing sugar[1] in solvent-extracted bark	61.3	61.6	57.5	43.4	41.2
Fermentable sugar[2] in solvent-extracted bark	47.3	43.4	39.7	33.8	32.0
Fermentable sugar calculated to unextracted bark basis	30.1	26.6	20.8	20.3	18.3

[1]The reducing sugar was obtained by hydrolysis of the bark with sulphuric acid, and was calculated as glucose.

[2]Represents the sugar fermentable with baker's yeast.

dian white spruce has been carried out by Harwood and Purves (19). These workers have isolated and identified, amongst other products, some of the fatty acid components of the methanol-soluble fraction of the bark. At the Forest Products Laboratory, Ottawa, studies were made of the carbohydrates in various Canadian barks. Table 26 shows the reducing and fermentable sugars in barks from balsam fir, black spruce, white spruce, eastern hemlock, and Douglas fir (8). Solvent-extracted western red cedar outer bark was found to contain 37.3 per cent glucose, 2.4 per cent mannose, 0.7 per cent galactose, and 7.4 per cent xylose (9).

Uses for Bark

Bark is still essentially a waste material, only limited uses having been found for it. Some pulp mills burn waste bark for power purposes; however, the use of bark as a fuel is complicated by the fact that it is usually very wet, and considerable water has to be removed prior to burning.

Specific uses have been developed for certain barks. For example, tannins are recovered from a number of barks, as previously described in this chapter. A company in the United States has recently developed a commercial method of reducing Douglas fir bark (46) into various fractions by physical methods. These fractions are being advertised for use in insecticides, soil conditioners, adhesives, etc. A product, sodium palconate, obtained by alkali extraction of redwood bark (24) is reported to be effective as a dispersing agent and in controlling viscosity and water loss in oil-drilling operations. From the bark of cascara a water-soluble concentrate, used for medicinal purposes, is prepared (7). There are a number of other minor products that are obtained from different barks throughout the world.

The pulping of bark by chemical methods in general gives low yields of pulp with high consumption of chemicals. Mechanical fibres from long-fibred barks, such as redwood and western red cedar, can be used as low-grade pulp products. Proposed uses for disintegrated barks are in insulating board (8), sheathing, bottle wrappers, deadening felts, chipboard, and boxboard (26).

There is no doubt that, as knowledge of the chemical and physical properties of bark increases, more uses will be found for the large volumes of bark now wasted.

WOOD AS A FUEL

As WOULD be expected in a country like Canada, where much of the land remains uncleared and covered with forest growth, wood is one of the chief materials used as fuel. According to statistics (42), the production of fuelwood in Canada in 1948 was 9,529,510 cords* valued at $49,535,855 and equivalent to 762,361,000 cubic feet of timber. This represents 23.84 per cent of the total volume, and 8.45 per cent of the total value of timber cut in 1948. These figures indicate the importance that fuelwood plays in the utilization of Canadian forests.

Fuelwood is a bulky commodity of low price and consequently it is ordinarily uneconomical to use it at long distances from the source of supply. Hence, it is largely utilized on farms and in rural communities, where the source of supply is close at hand, and where the cost of coal and other fuels is high. In such districts, it is the main fuel, since many farms possess a woodlot and farmers can cut fuelwood in their spare time.

Fuelwood is preferably produced in Canada from hardwoods, but any species of either softwood or hardwood may be used. It is generally cut during the winter or early spring, but can be cut at any season. If there is any desire to allow the stumps to resprout, which is often the case with such species as maple or birch, winter or early spring cutting is best, as then the new sprouts will be old enough to withstand winter-killing.

Considerable quantities of mill waste are used for fuel purposes in districts where the mills are in close proximity to a large number of consumers. In British Columbia, mill waste in the form of sawdust, slabs, and edgings is used for domestic heating, while hogged fuel is also available for industrial use. Sawdust and hogged fuel are sold by the unit, which is 200 cubic feet.

Fuelwood is often burned in stoves or Quebec heaters, but is burned most efficiently in furnaces specially designed to take ordinary cordwood lengths. To burn sawdust in domestic furnaces it is necessary to affix a Dutch oven extension and a hopper to the furnace. On burning, a standard cord of hardwood yields about 60 pounds of ashes (43), whereas a ton of American anthracite coal yields from 200 to 300 pounds of ashes.

*This does not include mill waste used as fuel.

The chief sources of fuelwood are as follows:

(1) *Trees that could often be better utilized for other purposes,*
(2) *Thinnings and improvement cuttings,*
(3) *Branches, tops, etc., left over from lumbering operations,*
(4) *Wood cut in the process of clearing land to be used for agricultural purposes,*
(5) *Mill waste, i.e., slabs, edgings, sawdust, etc., from lumber mills.*

Determinations of the calorific value per pound of oven-dry wood have been carried out by various workers. Nichols and Mohr (34) find the value for Canadian beech to be 8,500 B.T.U.* Jenkins and Guernsey (23), working on British Columbia woods, give figures from which it is calculated that the average value for western hemlock, Douglas fir, and Sitka spruce is 8,600 B.T.U. As a result of an extensive investigation along these lines, Krishna and Ramaswami (27) give the average for 150 species of Indian woods as 9,030 B.T.U., this figure being calculated on the basis of ash-free, oven-dry wood. If no allowance is made for the ash content, the average value for Indian species would be not much above the values found for Canadian species.

The values given above support the generally accepted statement that the calorific value per pound of oven-dry wood is approximately the same for all species, being roughly about 8,500 B.T.U. Hence it would at first seem best to measure firewood by weight. But ordinary firewood is not oven-dry; it contains moisture in widely varying amounts, ranging from about 20 per cent in well-seasoned wood to 70 per cent or more in green wood; so the number of B.T.U. per pound is a variable quantity. Accordingly, it is much more convenient to measure firewood by volume, the usual unit being the standard cord.

The fuel value of a cord of wood is dependent on:

(1) The actual volume of solid wood. The volume of a standard cord is 128 cubic feet, but the volume of the actual woody material present is variable. It is influenced by such factors as the manner of stacking (it is possible to stack the same pieces so as to occupy varying amounts of space), the length of the pieces, and their average diameter. The amount of space taken by a given quantity of wood before being split varies from that occupied by the same wood after splitting. Long pieces cannot be stacked as closely as short pieces, because of the greater effect of crooked and knotty parts. If the length is constant, the volume of solid wood per cord increases with increased diameter of the pieces. It is estimated that the average content of a standard cord of split wood is 85 to 90 cubic feet of solid wood.

(2) The specific gravity of oven-dry wood. If two cords of wood, not of the same species, contain equal volumes of woody material at the same moisture content, then, as the calorific value per pound of the dry wood of all species is approximately the same, the cord of that species which has the greater specific gravity (calculated on the oven-dry basis) will have the greater fuel value. Hence, a cord of sugar maple (specific gravity 0.6) or yellow birch (S.G. 0.57) is about twice as valuable as a cord of balsam fir (S.G. 0.33) or white cedar (S.G. 0.30).

(3) The percentage of resins and other extractives in the wood. As previously stated, the calorific value per pound of oven-dry wood is approximately constant for all species. Exceptions are those species that contain relatively high percentages of resins and other extractives; in such cases the calorific value is above the average, being sometimes as much as 12 per cent (43) higher.

(4) The moisture content of the wood. There is not so great a difference in the fuel values of green and seasoned wood as might be expected. A cord of green wood contains the same amount of woody material when oven-dried as when green, so the amount of heat produced on burning is exactly the same. However, some of the heat produced from the burning of green wood is not available for use, since it is used up in evaporating the moisture present and heating it to the temperature of the flue gases. For example, if there are 2 cords of wood of the same species having the specific gravity, when oven-dry, of 0.6, containing 15 and 60 per cent moisture respectively, the heating value of the latter is 93.1 per cent* of the former.

*One B.T.U. (British Thermal Unit) is 1/180 of the heat required to raise one pound of water from 32°F. to 212°F.

*Assuming that the loss of heat per pound of water is 1,220 B.T.U., as given by W. B. Campbell, "The Fuel Value of Wood", Forest Products Laboratories of Canada; and that one pound of oven-dry wood yields 0.48 pounds of water when burned, according to Bulletin No. 753, U.S. Dept. of Agriculture, p. 28.

Most purchasers are more interested in a comparison of firewood with coal or coke for heating domestic houses than with actual calorific values. In Table 27 by J. D. Hale (14) such a comparison is made between American anthracite coal and various Canadian woods, the calorific value of the coal being assumed to be 12,900 B.T.U. per pound, and the moisture content of the wood 25 parts per 100 parts of oven-dry wood.

By using the results of practical tests carried out by Jenkins and Guernsey (23) on sawdust, and Malloch and Baltzer (31) on coal, it is estimated that one ton of American anthracite coal is equivalent in heating effect to 2.58 units of green Douglas fir sawdust, the moisture content being 60 parts per 100 parts of oven-dry wood.

HEATING VALUE OF THE MORE IMPORTANT CANADIAN WOODS

TABLE 27

HARDWOODS

SPECIES	GROSS CALORIFIC VALUE (Millions of B.T.U. per air-dry cord)	NUMBER OF AIR-DRY CORDS (8 feet by 4 feet by 4 feet) Required to Equal 2,000 Pounds Anthracite Coal
Alder, red (*Alnus rubra*)	17.4	1.80 to 2.17
Ash, black (*Fraxinus nigra*)	22.6	1.39 to 1.67
Ash, green (*Fraxinus pennsylvanica* var. *lanceolata*)	22.1	1.42 to 1.70
Ash, white (*Fraxinus americana*)	25.0	1.25 to 1.50
Aspen, trembling (*Populus tremuloides*)	17.7	1.77 to 2.13
Basswood, (*Tilia americana*)	17.0	1.85 to 2.22
Beech (*Fagus grandifolia*)	27.8	1.13 to 1.35
Birch, white (*Betula papyrifera*)	23.4	1.34 to 1.60
Birch, yellow (*Betula lutea*)	26.2	1.20 to 1.44
Butternut (*Juglans cinerea*)	17.4	1.80 to 2.17
Cherry, black (*Prunus serotina*)	23.5	1.34 to 1.60
Chestnut (*Castanea dentata*)	20.2	1.55 to 1.87
Cottonwood (*Populus deltoides*)	16.8	1.87 to 2.25
Cottonwood, black (*Populus trichocarpa*)	15.5	2.00 to 2.40
Elm, rock (*Ulmus Thomasi*)	32.0	0.98 to 1.18
Elm, slippery (*Ulmus rubra*)	25.4	1.24 to 1.48
Elm, white (*Ulmus americana*)	24.5	1.28 to 1.54
Hickory, bitternut (*Carya cordiformis*)	29.2	1.08 to 1.29
Hickory, shagbark (*Carya ovata*)	30.6	1.03 to 1.23
Maple, Manitoba (*Acer Negundo*)	19.3	1.63 to 1.95
Maple, red (*Acer rubrum*)	24.0	1.31 to 1.57
Maple, silver (*Acer saccharinum*)	21.7	1.45 to 1.74
Maple, sugar (*Acer saccharum*)	29.0	1.08 to 1.30
Oak, black (*Quercus velutina*)	28.2	1.11 to 1.34
Oak, bur (*Quercus macrocarpa*)	28.2	1.11 to 1.34
Oak, red (*Quercus borealis*)	27.3	1.15 to 1.38
Oak, white (*Quercus alba*)	30.6	1.03 to 1.23
Poplar, balsam (*Populus balsamifera*)	17.2	1.83 to 2.19
Poplar, largetooth aspen (*Populus grandidentata*)	18.2	1.73 to 2.07

SOFTWOODS

SPECIES	GROSS CALORIFIC VALUE (Millions of B.T.U. per air-dry cord)	NUMBER OF AIR-DRY CORDS (8 feet by 4 feet by 4 feet) Required to Equal 2,000 Pounds Anthracite Coal
Cedar, eastern white (*Thuja occidentalis*)	16.3	2.30
Cedar, western red (*Thuja plicata*)	16.8	2.25
Douglas fir (*Pseudotsuga taxifolia*) (coast type)	24.3	1.50
Douglas fir (inland, or mountain type)	22.2	1.65
Fir, amabilis (*Abies amabilis*)	16.5	2.30
Fir, balsam (*Abies balsamea*)	15.5	2.40
Fir, grand (*Abies grandis*)	17.4	2.15
Hemlock, eastern (*Tsuga canadensis*)	17.9	2.10
Hemlock, western (*Tsuga heterophylla*)	19.3	1.95
Larch, western (*Larix occidentalis*)	26.5	1.35
Larch, eastern, or tamarack (*Larix laricina*)	24.0	1.50
Pine, jack (*Pinus Banksiana*)	21.6	1.75
Pine, lodgepole (*Pinus contorta* var. *latifolia*)	20.1	1.85
Pine, ponderosa (*Pinus ponderosa*)	22.1	1.70
Pine, red (*Pinus resinosa*)	19.7	1.90
Pine, western white (*Pinus monticola*)	18.6	2.05
Pine, white (*Pinus Strobus*)	17.1	2.20
Spruce, black (*Picea mariana*)	19.1	2.00
Spruce, Engelmann (*Picea Engelmanni*)	17.6	2.15
Spruce, red (*Picea rubens*)	18.1	2.10
Spruce, Sitka (*Picea sitchensis*)	15.9	2.35
Spruce, white (*Picea glauca*)	16.2	2.30

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SECONDARY WOOD-USING INDUSTRIES

by J. B. PRINCE

THE forest products industries may be divided into primary and secondary groups. The industries of the primary group use logs as their raw material, whereas those of the secondary group use the products of the primary group for further manufacture, reduction, or treatment. For example, the pulp industry utilizes logs as raw material, while the paper industry uses the pulp produced from these logs for further manufacture. Among other important industries in the first group may be noted the sawmill, veneer mill, charcoal, and wood distillation industries. Representative of the secondary group are plants turning out furniture, cooperage and other types of containers, and planing mills.

The relative importance of the two groups can be gauged by considering the man-hours or salaries and wages involved (2). In 1948, the value of lumber produced in Canada totalled $340,850,538. Wood, in the form of lumber, veneer, etc., is the principal raw material of the secondary wood industries. Expenditures for this purpose, in 1948, amounted to $223,652,196. Salaries and wages of $123,105,331 paid, in the same period, by the secondary wood-using industries compare very favourably with the total of $95,065,676 paid by the sawmilling industry. The high wage payments can best be understood by considering, for example, the more intensive processes of manufacture in the furniture industry.

In view of the complexity and variety of products turned out by the secondary group, it is frequently difficult to classify plants or groups of plants into precise categories. Table 28 is an attempt to break down the secondary industries into classes which are based broadly upon the similarity of raw materials required.

From the aspect of use by the secondary industries, woods can be broadly classified into three groups, (1) those characterized by aesthetic appeal, (2) those possessing strength and durability, and (3) those where characteristics such as ease of nailing and nail-holding power are the deciding factors, rather than grade or quality. Characteristics such as ease of working are important for almost all uses. The above aspects of use may be exemplified, to some extent, by (a) furniture, (b) boat-building, and (c) container industries. Certain use requirements may occasionally necessitate the consideration of particular qualities beyond the general requirements.

NORMAL TRADE GROUPING OF SECONDARY WOOD-USING INDUSTRIES*

TABLE 28

Industry	Additional Items Manufactured or Processed
Sash, door, and planing mill	*Boxes, shooks, furniture, hardwood flooring, mouldings.*
Furniture	*Mouldings, frames, toys, refrigerators.*
Boxes and baskets	*Baby carriages, boats, caskets, excelsior, furniture.*
Veneer and plywood	*Baskets, boxes, doors, dowels, shooks.*
Hardwood flooring	*Boxes, dowels, furniture, lumber.*
Wood turning	*Baseball bats, hockey sticks.*
Cooperage	*Boxes, lumber, pails, tanks.*
Coffins and caskets	*Boxes, flooring, lumber, mouldings.*
Boat-building	*Aircraft parts, boxes, furniture, ladders.*
Lasts, trees, and wooden shoe findings	*Patterns, woodenware, models.*
Woodenware	*Baskets, doors, furniture.*
Wooden refrigerators	*Furniture.*
Carriages, sleighs, and vehicle supplies	*Auto bodies, furniture.*
Beekeepers' and poultrymen's supplies	*Fencing, doors, sash, toys.*
Excelsior	
Miscellaneous wood-using	*Sporting goods, toys, refrigerators.*
Distillation	*Charcoal.*
Wood preservation	*Ties, telephone poles, mine timbers.*

*Classification used by Bureau of Statistics, Canada.

The wood-using industries, as we know them today, are almost entirely an outgrowth of the industrial revolution. Prior to that development, shipbuilding was the only sizeable craft in which workers were concentrated in large establishments, although during the eighteenth century fine furniture tended increasingly to be produced in comparatively large workshops which were generally founded and directed by some outstanding craftsman. Aside from these instances, woodworking was practised by individual craftsmen working for the most part in their own homes, although in the building trades they were naturally employed at the point of construction, where all preparation of lumber was done on the spot, and almost entirely by hand. With the introduction of steam power, and the consequent development of woodworking machines, the factory system as it exists today rapidly came into being.

Wood-using industries appear for the first time in the census of Upper and Lower Canada in 1851. As these industries assumed a more prominent place they were dealt with in considerable detail. Carriages and wagons, followed by furniture and cooperage, were the leaders in this field. While the manufacture of vehicles continued to increase for many years, its relative importance gradually lessened with the growth of other wood-using industries. With the advent of the automobile this industry steadily lost ground.

One of the earliest forms of large-scale utilization was the production (see Chapter 8) of potash from wood. The potash industry was a very important one in Canada from almost 1800 to 1870. During this time, large areas of virgin forest were cut, for the most part to clear the land for agriculture. About 1870, the exploitation of natural deposits of potassium salts in Germany and elsewhere began, and wood has since ceased to be an important source of this material. Some conception of the volume of wood involved in this trade may be gained when it is noted that 1,000 pounds of dry hardwood yield one to two pounds of potash, and that records (3) indicate that total Canadian exports of potash and pearlash (a refined form of potash) in 1850 amounted to 27,000,000 lbs.

FURNITURE INDUSTRY

THE manufacture of fine furniture is as old as civilization, but the furniture industry as we know it today is a child of yesterday, though the delvings of archaeologists have produced evidence that basic methods of construction were developed at a very early period. Such furniture, however, was the prerogative of the wealthy, or was constructed for use in public buildings, either ecclesiastical or secular. The masses of the people either possessed no furniture whatever or, if they did have any, it was of the simplest character and of extremely rough

and sturdy construction. Broadly speaking, this situation continued up to the age of steam, when the application of powered machines to the production of work formerly turned out slowly and arduously by hand made it possible for all classes of the community to furnish their homes throughout at a reasonable cost. Styles and designs are still based, to a considerable extent, on the work of the great periods and designers, although of late years there has been an increasing tendency towards the production of strictly functional pieces not conforming to any past school or style.

The manufacture of furniture of the finest character, and particularly the use of wood for this purpose, is perhaps more an art than a craft. To a high degree, the use or exploitation of certain woods is inextricably interwoven with the development of styles and types of furniture associated with the various periods in history. The preponderant use of the darker-coloured woods, such as mahogany, black walnut, and oak, has resulted in such, or similar species, becoming the chief criterion of desirability in furniture. This demand, in time, brought about the development of what is now an art in itself—the art of staining and finishing to imitate, with less expensive species, the more costly woods.

In Canada, the industry was mainly located near the large black walnut, white oak, and black cherry growing in the virgin hardwood stands of south-western Ontario. With the disappearance of these species in commercial volume, and the necessity for importing the more decorative woods, there has been a tendency for the industry to disperse more widely.

The use of yellow birch, a very adaptable species that can be readily stained to resemble other woods, has increased. The large reserves of sugar maple have been utilized increasingly for the production of so-called colonial-type furniture. Other species, such as elm, have important uses for certain of the less expensive types of furniture, and many others are used for secondary or minor purposes. However, the industry generally is today largely dependent upon supplies of imported hardwood lumber for an appreciable percentage of the better-class furniture.

During the Second World War, the adaptability and strength qualities of laminated construction, veneers, and plywoods led to extensive use of such

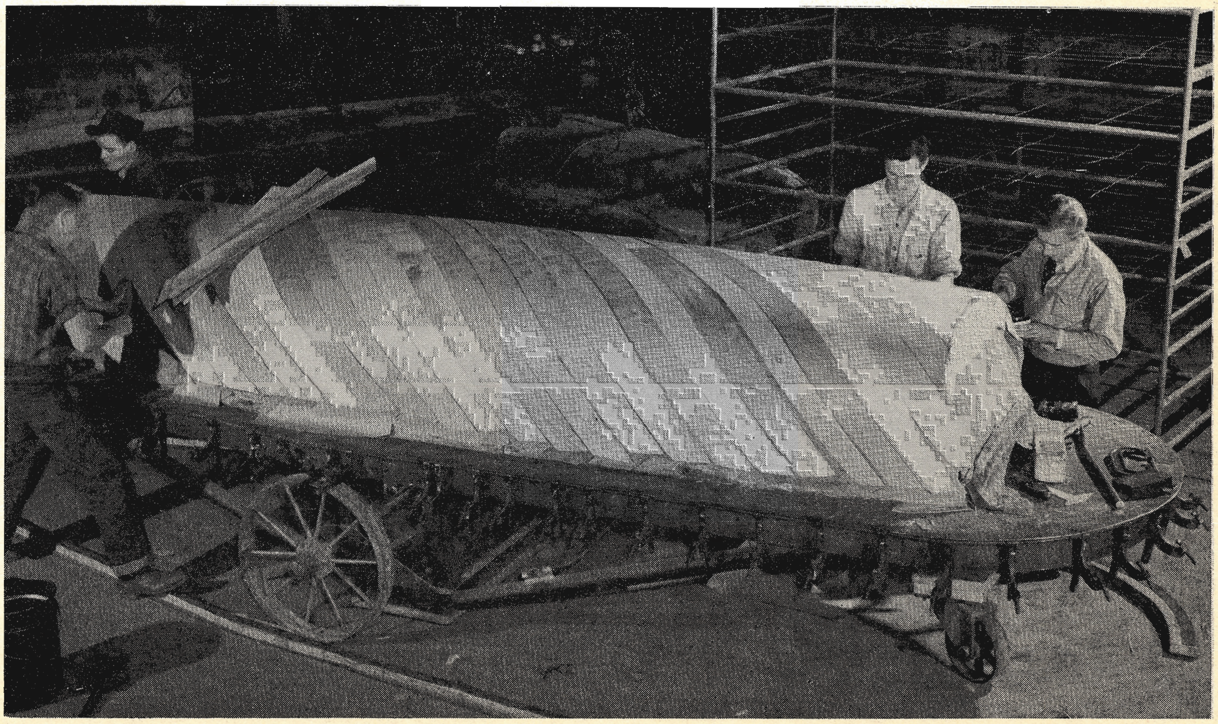

PLATE 85.—Assembling Plywood Boat with Birch Veneer.

materials in the production of aircraft and aircraft components. The skilled workmanship associated with the production of fine furniture was ideally adapted to the exacting specifications governing aircraft work. Such war-time dislocation of normal operation brought its own compensations when peace returned. Many plants equipped with outdated machinery, and lacking knowledge of modern production practices, emerged from the war admirably re-equipped to resume peace-time operation.

The Furniture Woods

A few woods combine most of the desirable properties necessary for fine furniture, whereas others possess these qualities in varying degrees. Some woods are readily workable, others have the strength required for use in structural parts, and some species possess the beauty desirable for exposed surfaces. The problem is to choose the wood or woods which best meet the requirements for the service and condition to which they are subjected, due balance being maintained between the economic, structural, and aesthetic factors.

Walnut—Belonging to the genus *Juglans*, walnut is almost an ideal wood for furniture, because it combines the many qualities which make for beauty, strength, and durability. Records show that it was used from very early times in many parts of the world.

Black walnut is the wood known as walnut today in Canada, and much furniture is made from the solid or veneered wood. Stumps or burls, abnormal growths in which the grain is very irregular, are usually highly figured and are used when beauty of pattern is desired, almost always as veneers. Other patterns come from the crotch where a limb joins the trunk, although such veneers are more susceptible to checking than the others.

Walnut combines moderate weight with strength, seasons and works well, holds up under use, and has beautiful figure and colour.

Butternut, another member of the genus *Juglans*, although usually plain in figure, takes a fine finish and is a beautiful and serviceable wood.

A number of woods have been called walnut and given a descriptive prefix. In some cases the prefix is proper; and in others, where the wood named belongs to a genus other than *Juglans*, it is misleading. The butternut, and the American, English, Persian, French, Italian, Spanish, Russian, Turkish, Circassian, Caucasian, Japanese, and Bolivian walnuts are all true walnuts, belonging to the genus *Juglans*.

Oak—The ruggedness of oak, which enables it to stand up well against abuse, recommends it for purposes involving hard and constant use. Oak furniture, massive in form and mellow in finish, is particularly favoured for dining-room and bedroom use. Many designs in oak are traceable to the Tudor and Jacobean periods of English history, and to French provincial styles.

Quarter-sawn white and red oak, showing the characteristic and attractive 'flake', has always been favoured for furniture.

Maple—The need of the colonial period settlers was for simple, substantial furniture, which could be made from timber available locally, and maple was one of the most favoured woods. It is still considered one of the choicest furniture woods, and is much used for reproductions of early colonial pieces, which are becoming increasingly popular.

Maple is used for bedroom and dining-room suites, and occasionally for living-room furniture, such as tables, chairs, and sofas. Because of its hard character and ability to take a smooth finish, it is likewise much used for extension table slides and other movable parts. In the eighteenth century it was used frequently as an inlay in mahogany. Its figure is usually straight, although wavy, curly, and bird's-eye patterns (the latter usually found in sugar maple) are much prized.

PLATE 86.—Box of Bird's-eye Maple.

Birch—Birch, also one of the early colonial cabinet woods, possesses an attractively figured grain that is enhanced by the modern stain finishes to which this wood is especially adapted. Like maple, birch

is hard and will retain a fine finish for a long period. It is specially adapted for use in bentwood designs.

The species commonly employed in furniture is the yellow birch. Sweet birch is also used, and ordinarily no effort is made to separate the lumber of these two closely related species. Other birches, including white and western white, are also used to some extent.

Ash—The properties of ash make it an acceptable furniture wood. In spite of this fact, ash is not classed among more important species, although used to some extent in the manufacture of medium grades of tables, chairs, and bedroom furniture.

Basswood —This species is eminently suited for core-stock to be covered with harder and more decorative woods. It is also employed for tops of kitchen tables and for partitions in drawers and other secondary parts of furniture.

Beech—Beech lacks pronounced grain or figure, but is strong and has excellent wearing qualities. It is much used in unexposed parts of furniture, where its strength and hardness make it a most suitable material for structural components.

Black Cherry—Black cherry was one of the favourites of early Colonial times because of its ability to "stay put" with minimum warping, and its good wearing qualities, combined with an attractive reddish-brown colour which mellows with age and exposure. Cherry is today relatively scarce, and, consequently, seldom used.

Elm—Elm is frequently used for the framework of upholstered furniture. It is strong, able to stand shock, and holds screws well. It is also used for kitchen chairs, cabinets, and other types of less expensive furniture. Elm finishes well and has a characteristic and attractive wavy surface.

Red Alder—Selected lumber showing numerous aggregate rays produces an attractive pattern. Red alder finishes well and can be stained to resemble most of the more valuable woods. Owing to its uniform texture, it is used extensively in the manufacture of the better grades of unpainted furniture.

Poplar—The names "poplar", "aspen", and "cottonwood" are given to various species of the genus *Populus*, whose woods are generally similar in physical properties and appearance. Poplar lumber is an important raw material for the concealed parts of all kinds of furniture and for exposed parts of less expensive types.

Imported Furniture Woods

Mahogany—True mahogany belongs to the genus *Swietenia*, indigenous to tropical America, or the closely related genus *Khaya* of West Africa. Mahogany does not warp easily, and works and takes stain well.

A great many unrelated species are sold under the name of mahogany, to take advantage of its enviable reputation as a furniture and decorative wood. Primavera, sometimes called white mahogany, which comes from Mexico and Guatemala, resembles mahogany somewhat in grain, but is creamy yellow in colour. The so-called Philippine mahogany belongs to the genus *Shorea* and may be encountered in the trade as tanguile or lauaan.

Purple Heart—Amaranth or violet wood as it is sometimes known, derives its name from its colour; it is obtained from the genus *Peltogyne* native to central and South America. It is used mainly for inlay work.

Ebony—Ebony is a name applied to many black or blackish woods, although it is only properly applied to those of the genus *Diospyros*. The wood is used for inlay work, handles, keys of musical instruments, and like purposes, and usually is obtained from Southeast Asia.

Rosewood—Obtained from the genus *Dalbergia*, rosewood is a decorative, hard, heavy, and usually straight-grained wood, red-purplish in colour, native to Brazil. It is one of the finest cabinet woods, taking a beautiful finish. Fresh heartwood has a mild, rose-like scent, from which fact the wood derived its name.

Teak—Teak (genus *Tectona*) comes mainly from Burma and the neighbouring areas of Southeast Asia. It is moderately heavy and hard, easily worked, and shrinks, swells, and warps little. Teak is resistant to white ants or termites, and contains a natural oil or resin which aids in retarding decay and in limiting shrinkage or swelling.

Willow, Rattan, Reed, and Fibre

Willow is the only native wood adapted to weaving. Formed into artistic designs by skilled craftsmen, it is much used for porch furniture.

Rattan is an Asiatic vine used for furniture weaving.

Reed, or stick reed, is the heart of rattan used in the same way as willow.

Fibre furniture is a paper product made from wood pulp which is formed into strands, sometimes over steel wire, and woven on looms. It is then formed into furniture over wood frames.

SHIPBUILDING INDUSTRY

FROM a small beginning, the building of wooden ships reached its peak in Canada during the latter half of the nineteenth century, chiefly in the Maritime Provinces and Quebec. With the advent of steam and the use of steel, wooden shipbuilding gradually diminished. The industry has to some degree been revived as a result of the demand during the two world wars, but the use of wood is now largely confined to the construction of smaller vessels.

Many stories are related as to the longevity of wooden ships. It is interesting to note that an in-

PLATE 87.—Schooner Under Construction, Lunenburg, N.S.

vestigation carried out some time ago by shipping registry officials of Great Britain showed, recorded on their books, twenty-four English wooden ships over 100 years old, and thirteen over ninety-five years old. The same source also notes that the "Victory", launched in 1765, is beyond doubt one of the oldest warships in existence.

The ready sale and world-wide demand for the products of Canada's shipyards was ample proof of their staunchness and workmanship, and of the quality of their timbers. One source of information, referring to the building of two ships on the Miramichi River in the early nineteenth century, states (1): "From the building of these two schooners the Province of New Brunswick dates its shipbuilding industry. In the early days the forests of the province supplied timber of large size in any quantity for building ships of the first class. Such ships were constructed chiefly of black birch (yellow birch) and larch or hackmatack. The black birch was used for the keel, floor, timbers, and lower planking. Larch or hackmatack was used for all other timbers, knees and upper planking. American and white oak were imported for stems and posts for the best class of ships and pitch pine for the beams. White pine was used for the cabins, interior finish, and the mast. Black spruce furnished as fine yards and topmasts as any in the world. Elm, pitch pine, maple, cedar, and spruce were all used in the construction of ships of the second class and small vessels."

Certain wood species have come to be so closely associated with shipbuilding that tradition in some instances deems them essential. Included in this category are such woods as teak, white oak, rock elm, and mahogany. The peculiar qualities that make a particular species desirable for certain uses are, with scarcity, increasing knowledge, and familiarity with other woods, tending to some extent to become less important. For any use, in addition to consideration of the essential qualities, the selection of a certain species should be determined by the many other factors involved.

CONTAINER INDUSTRY

THE manufacture of shipping containers (see Chapter 12) is an important section of the wood-using industry. Wood as the raw material represents the most important requirement of the industry in such forms as lumber, plywood, veneer, or paper.

Lumber used for shipping containers is largely low-grade material or small-dimension stock, of little use to any other industry. The lack of emphasis on quality is explained by the circumstance that the strength of a box or crate is much more closely related to the strength of its fastenings, usually nails, than to the structural strength of the wooden members from which it is constructed. The size of lumber required for all but the largest crates would be too small for structural purposes and the appearance desirable for the furniture industry would be utterly wasted in a box or crate. So long as certain serious defects are absent, any lumber available, and not acceptable for more exacting purposes, may be utilized for box and crate construction, except in certain special cases. Such lumber is preferably the least expensive. The ideal shipping container will give satisfactory service and yet be low in cost.

TABLE 29

Thicknesses of Box Boards Obtained by Resawing or Dressing Lumber 4/4 to 7/4 Inches Thick, Adopted by the Box Section of the Canadian Lumbermen's Association and the National Wooden Box Association.

Box Boards, Thickness in Inches	Finish of Boards	Number of Boards Obtained	Rough Lumber, Thickness in Inches
3/16	Rough, S1S	3	4/4
1/4*	Rough	3	4/4
1/4	S1S	3	4/4
5/16	Rough	3	5/4
5/16*	S1S	3	5/4
3/8	Rough, S1S	2	4/4
7/16	Rough	2	4/4
7/16*	S1S	2	4/4
1/2	Rough, S1S	2	5/4
9/16	Rough	2	5/4
9/16*	S1S	2	5/4
5/8	Rough, S1S	2	6/4
11/16	Rough	2	6/4
11/16	S1S	2	7/4
3/4	Rough, S1S	2	7/4
13/16	Rough, S1S, S2S	1	4/4
7/8	Rough, S1S, S2S	1	4/4
15/16	Rough, S1S	1	4/4
4/4	Rough	1	4/4
4/4	S1S	1	5/4

*These are commercial or merchantable thicknesses, with a reasonable variation permitted. If "full" thickness without variation is required, then the next greater thickness should be used.

If parts are to be "surfaced two sides and full thickness" also, use the next higher thickness of lumber except where specified in the list above.

Species of wood having physical and other properties sufficiently similar to be used interchangeably for box and crate construction are indicated in each of four groups in Table 30.

Grouping, According to Strength in the Air-Dried Condition, of Canadian Woods for Box Construction.

TABLE 30

Softwoods—

GROUP 1

Cedar, eastern	Pine, jack	Spruce, black
" western	" lodgepole	" Engelmann
Fir, alpine	" red	" red
" amabilis	" western white	" Sitka
" balsam	" ponderosa	" white
" grand	" white	

Hardwoods—

Ash, green	Maple, Manitoba	Poplar, balsam
Basswood	Poplar, aspen*	" black cotton-wood
Butternut	" large-tooth aspen	" cottonwood
Chestnut		

**Populus tremuloides* Michx.

GROUP 2

Douglas fir	Hemlock, western	Maple, silver
Hemlock, eastern	Larch, eastern	
	" western	

GROUP 3

Ash, black	Elm, slippery	Maple, red
Birch, white	" white	Oak, bur

GROUP 4

Ash, white	Elm, rock	Oak, black
Beech	Hickory, bitternut	" red
Birch, yellow	" shagbark	" white
	Maple, sugar	

PLATE 88.—Tobacco Hogsheads (spruce is largely used for slack cooperage).

For some applications, certain characteristics apart from the truly physical properties are important. Butter, for example, readily absorbs flavours from surrounding materials, and spruce is therefore generally acceptable for butter boxes as it does not impart any objectionable flavour (4). In packing articles of metal, other considerations arise; woods having a high acid content such as oak, chestnut, or western red cedar, may, particularly under humid conditions, cause corrosion of exposed metallic surfaces.

Defects which appreciably weaken lumber are dealt with in more detail elsewhere (page 114), the principal ones being knots, cross-grain, wane, checks and shakes, warping, and decay. The severity of service required of the container will determine the extent to which some defects can be tolerated.

Knots, if less than one-third the width of the board and not in a position to interfere with nailing, are not objectionable, except for the risk of a knot falling out. The contents will determine the importance of knot holes.

Cross-grain, if slight, is not important. It should not exceed 1″ in 10″ for overseas shipment or 1″ in 6″ for overland transport.

Wane (see definition, page 19) may not be important if sufficient nailing area remains, unless the contents demand closely fitting panels. Wane weakens a board, more particularly if it occurs on a face, as the actual cross-section is reduced. Wane is not permissible, generally speaking, in boxes, but in crates its presence may not be important, provided always that the full thickness of the board is present over a sufficient width to permit face nailing, and that the quality of the board is otherwise acceptable.

Checks and splits must be considered on their merits. If it is possible to nail the board as if it were separated into two boards, then the check or split is of little importance.

Warp or twist is serious only if undue strain is developed in pulling boards into shape in making the box.

Decay is a serious defect and affected material should not be used.

Seasoning—Box shooks are commonly cut green but they must be properly seasoned to a moisture content adapted to the region in which they will see service.

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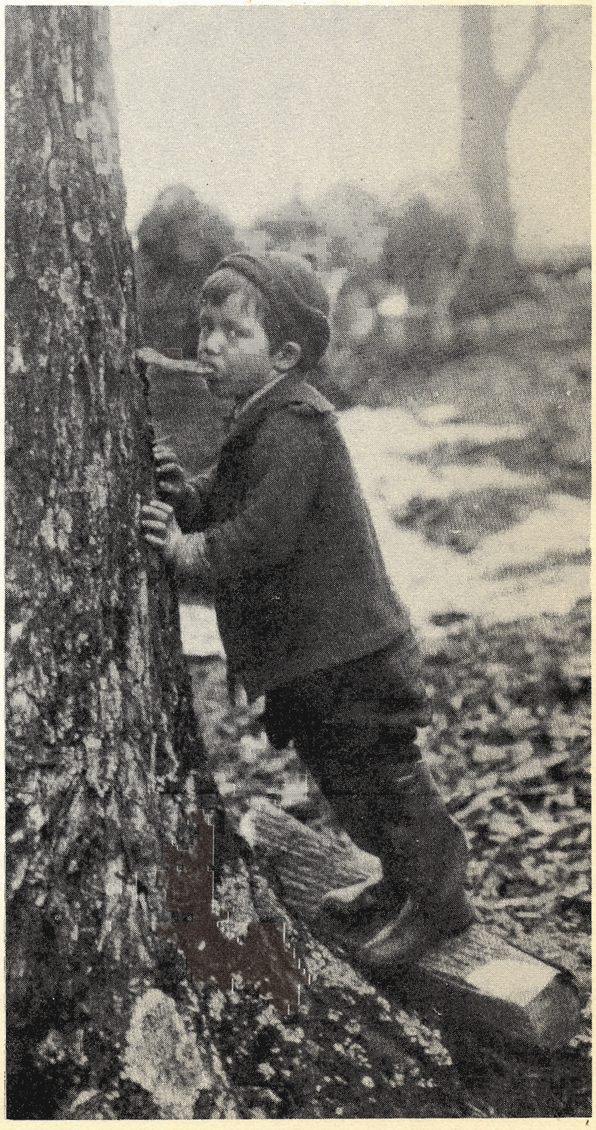


Direct Utilization

The Beauty of Wood in the Home.

VENEERS, PLYWOODS, AND WOOD ADHESIVES

by D. G. MILLER

Properties of Plywood

PLYWOOD is a composite wood product consisting of layers of wood glued together with the grain in alternate layers at an angle—usually a right angle. An almost infinite variety of plywood constructions is possible, depending upon such factors as the number and thickness of plies, the species used, and the arrangement of the plies.

In most plywood, an odd number of plies is normally used. This gives a balanced construction and reduces any tendency to cupping. When an even number of plies is glued together with the grain of alternate layers at right angles, the difference in shrinkage in the direction of the grain and across it causes cupping in the finished panel.

The outside layers of plywood are called the faces, the central ply is known as the core, and, where more than three plies are used, those with grain at right angles to that of the faces are called cross-bands.

There are two basic types of plywood in common use, the all-veneer construction and the lumber-core construction, both illustrated in Figure 34.

The all-veneer type of plywood is preferable for general construction use, in which maximum strength and dimensional stability are required. The better and clearer grades of veneer are used for the faces and the less desirable grades for the inner layers. In plywood with three veneer plies, if the core veneer is made equal in thickness to the combined two face veneers, a balanced construction is obtained, and the plywood will have approximately the same tensile strength in both directions. In bending, however, this plywood is stiffer when the span length is parallel to the face plies. For equivalent strength in bending in both directions, the core ply should be approximately three-quarters of the total thickness of the plywood. It should be noted that plywood can never have a strength in bending or in tension equal to that of ordinary wood of the same species, quality, dimensions, and moisture content. The greater the number of plies for a given thickness, the more nearly equal are the strength properties in the two directions of the panel. For aircraft skins and some structural purposes, the plywood may consist of three veneers of equal thickness. As a consequence, this plywood is appreciably stronger in the direction of the face plies than in the transverse direction, and is more flexible in bending across the grain of the face plies. Aircraft plywood is frequently made with the direction of the grain of the face plies at an angle of 45° to the length of the panel. The alternate plies are placed at right angles to each other. This construction is more expensive, but provides better resistance to torsional stresses.

Lumber-core plywood consists of a thick core of sawn lumber with cross-banding and face plies. The core is normally made of strips of lumber ¾ inch thick and 3 to 4 inches wide, which are edge-glued. This type of construction does not produce the uniform strength characteristic of veneer construction, because the strength of the core predominates. However, plywood of lumber-core construction is

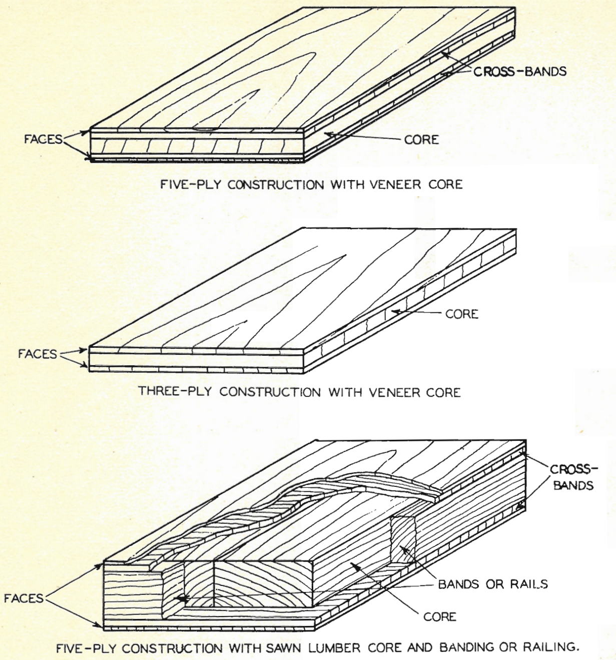


FIGURE 34.—Standard Plywood Construction.

more suitable for the production of furniture and allied products, because the thick lumber core permits dowelling, dovetailing, and other cabinet-making operations. The core is often banded along the edges with veneer or lumber of the same species as the face veneer.

Plywood can be specially designed for the particular use for which it is required. It may be designed for strength, for stiffness, for bending, for lightness, for beauty, for cheapness, or for other qualities. The following discussion is concerned with the general characteristics of plywood, particularly thin plywood made with the standard veneer construction.

Strength Properties

As compared to ordinary wood, the chief advantage of plywood is an equalization of strength properties along the length and width of the panel. Wood is considerably stronger and stiffer along the grain than it is across the grain. Plywood can be prepared which will have approximately the same strength in all directions, but it should be noted that the strength in one direction is increased at the expense of that in the other.

Approximate working stresses for plywood can be calculated by applying a suitable multiplying factor to the working stresses for the species used (1). The safe working stresses for Canadian wood species are given in Appendix Table 18; these stresses are for clear material free from defects, and a reduction factor appropriate to the estimated grade of material in the plywood should be used where necessary.

Tension and Compression Strength

When plywood is subjected to a tensile or compressive force, only those plies having their grain running in the direction of the force are considered effective in carrying the load; the tensile strength of the plywood is calculated on the safe allowable working stress in bending for the extreme fibre* for the species concerned, and the compressive strength is calculated on the safe allowable working stress of the species in compression parallel to grain. If the tensile stress is at an angle of $\pm$ 45° to the direction of the face grain, the strength is calculated on the full cross-sectional area of the plywood, using one-sixth of the safe allowable working stress in bending for the extreme fibre. In the case of a compressive force at an angle of $\pm 45°$ to the direction of the face grain, the strength of the plywood is calculated on the full cross-sectional area of the plywood, using one-third of the safe allowable working stress in compression parallel to grain.

Shear Strength Through Thickness

The full cross-sectional area is used in calculating the shear strength of plywood. If the stress is parallel or perpendicular to the direction of the face grain, the unit stress to be used is double the safe allowable working stress for ordinary wood in horizontal shear. Similarly, where the shearing stress is at an angle of $\pm 45°$ to the direction of the face grain, four times the safe allowable working stress for ordinary wood in horizontal shear is used as the unit stress.

Bending Strength

The approximate bending strength of plywood can be calculated by the following modified form of the flexure formula:

$$M = \frac{k.S.I.}{c}$$

*See Chapter 4, the Mechanical and Physical Properties of Canadian Woods in Relation to their Uses.

Where M = bending moment.
S = safe allowable stress for extreme fibre in bending.
I = moment of inertia computed on basis of plies parallel to span.
c = distance from the neutral axis to the outer fibre of the outermost ply having its grain parallel to the span.
k = 1.5 for three-ply plywood having the grain of the outer plies perpendicular to the span and 0.85 for all other plywood.

The deflection of plywood in bending may be calculated by the usual formulae, using as the moment of inertia that of the parallel plies plus 1/20 that of the perpendicular plies.

Dimensional Stability

Solid wood not only shrinks as it loses moisture, and swells as it absorbs moisture, but this movement is much greater across the grain than it is along the grain. Because in plywood approximately half of the wood grain runs in one direction and the other half at right angles, its tendency to shrink and swell is largely neutralized. Tests have shown that from a soaked to oven-dry condition, 3-ply panels shrink 0.45 per cent parallel to the face grain and 0.67 per cent across the face grain (2). Normally the variation of moisture content of wood indoors is not much greater than 4 per cent, and thus the dimensional change due to moisture is much less than the figures given above.

Splitting and Impact Resistance

Because of its cross-layer construction, plywood cannot be split in the plane of the panel. This characteristic is of particular importance, since it allows the use of nails, screws, or other fastenings very close to the edges of the panels. For the same reason, plywood has a greater impact resistance to blows perpendicular to its faces than ordinary wood, and the ultimate break-through is less sudden.

Bending Properties

Although it is designed to produce a flat panel, standard plywood made of veneers can be bent more readily than wood of the same thickness. The radius of curvature to which plywood can be bent depends upon its thickness, and is limited by the strength of the outer plies in tension and of the inner plies in compression. If plywood is made with a waterproof glue, its flexibility in bending can be increased by about 50 per cent by soaking or steaming.

The bending characteristics of plywood can be improved by means of special constructions such as 2-ply or by placing the inner layers at an angle of less than 90° to the outside face veneers.

Decorative Qualities

Apart from its structural properties, plywood offers exceptional decorative possibilities. The woods of certain species, such as mahogany, walnut, and oak, vary in colour and in texture and they offer an almost infinite variety of grain figure. By cutting thin veneers from these species and using the veneers for the face plies, the most economical use can be made of those woods possessing exceptional beauty. In many cases, unusual grain figures can best be revealed and utilized by cutting the wood into veneer. Lumber-core plywood is usually faced on one or both sides with a figured veneer. Successive sheets of such veneers may be joined together or matched so as to produce repetition of the grain pattern in such forms as book matching, slip matching, diamond matching, checkerboard matching, and butt matching.

MANUFACTURE OF VENEER

THE four main methods of cutting veneer, rotary cutting, half-round or stay-log cutting, slicing, and sawing are illustrated in Figure 35.

Rotary Cutting

Rotary cutting is by far the most important method of manufacturing veneer. It is used in the production of commercial veneers for plywood and containers, and also for cutting some figured veneers. In this process the log is centred and held by chucks in a massive lathe. The veneer is obtained by rotating the log against a pressure bar and a knife, which are held parallel to the axis of the log. The pressure bar, mounted just above the knife edge, prevents splitting of the veneer by exerting compression on the wood as it is fed toward the knife. The knife and pressure bar are automatically advanced at a rate set according to the thickness of the veneer required (3).

Logs which are to be converted into rotary-cut

veneer are selected for straightness, roundness, and freedom from knots and decay. The surface is carefully examined to ensure that there are no nails or other metallic objects present which might damage the knife. During storage, the logs must be kept wet to prevent end-checking and to inhibit the growth of wood-destroying fungi. In some cases, the logs are stored in a log pond, or they may be stacked and constantly sprayed with water.

When the logs are required in the veneer plant,

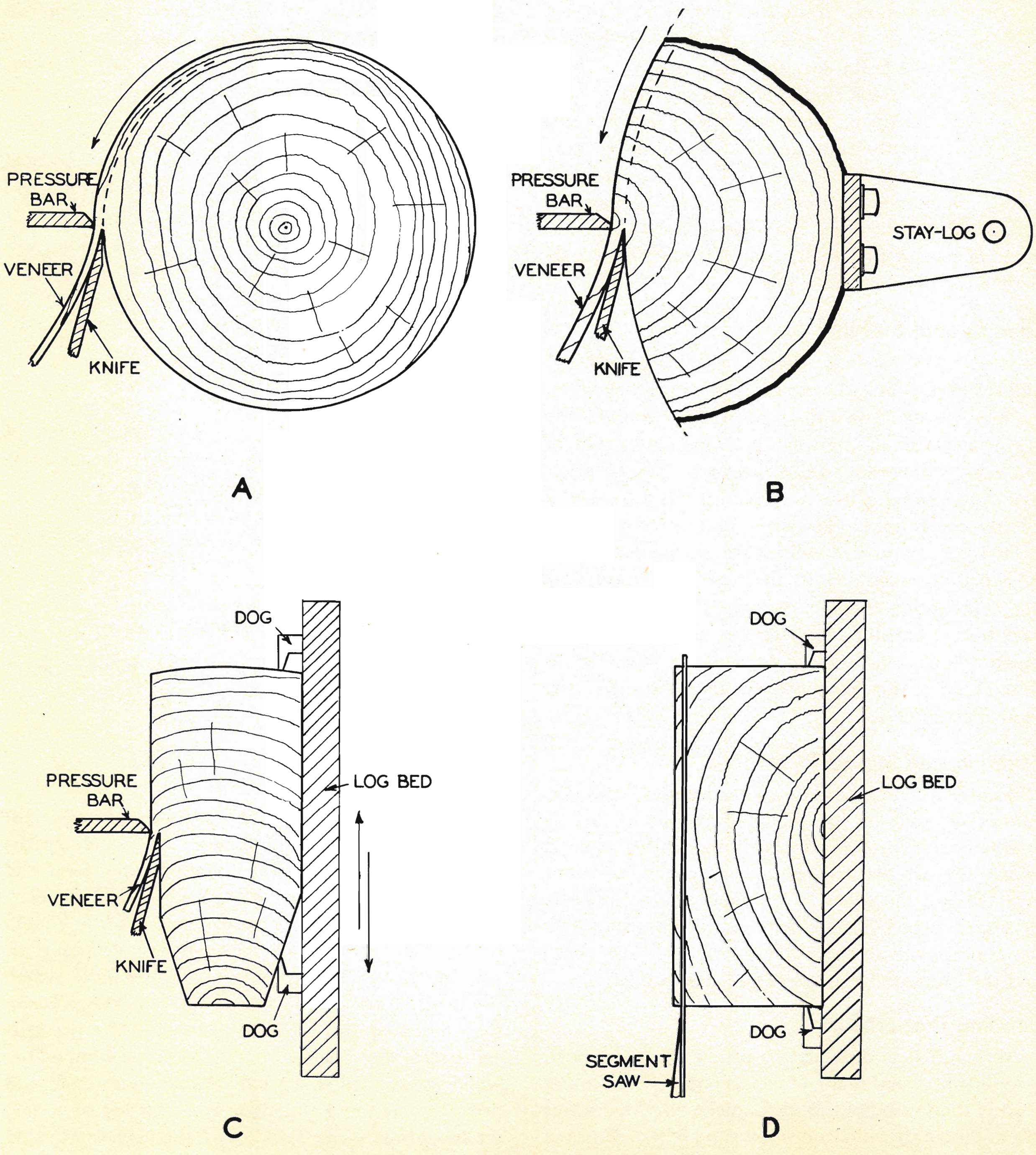


FIGURE 35.—Methods of Cutting Veneer.

A.—rotary-cutting; B.—half-round cutting with stay-log; C.—slicing; D.—sawing.

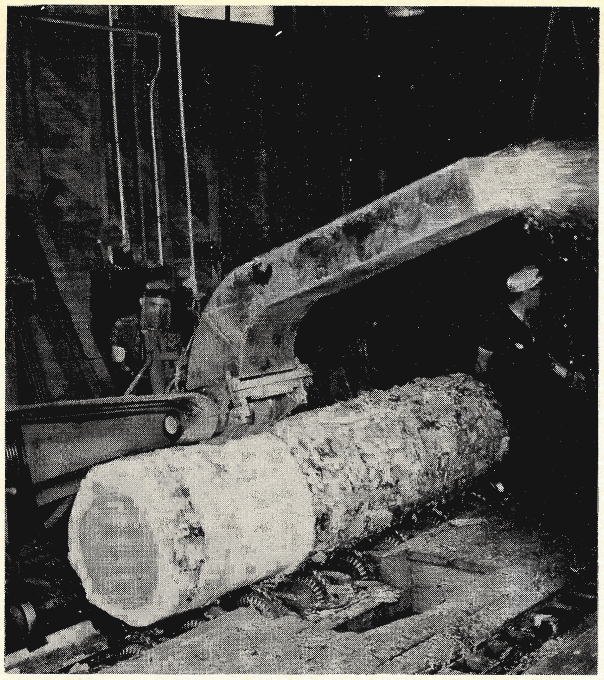


PLATE 89.—Barking and Rough-turning Veneer Log.

they are removed from storage and cut into bolts slightly longer than the length of the finished veneer sheets. The bolts are carefully selected from the log to avoid, as much as possible, defects and excessive taper. The bark is then removed from those species which do not require heat treatment. For other species, the barking operation is delayed until the bolts have been removed from the conditioning pits, as the heat treatment loosens the bark and permits its removal more readily.

The softening process consists of heating the logs by means of steam or hot water in pits or vats, which are usually made of reinforced concrete (4). The heat softens the wood, thus enabling the knife to cut smoothly with minimum power consumption. Wood that is not sufficiently soft, either naturally or by heat treatment, has a tendency to cut with a rough finish, since many of the fibres are torn.

Considerable difference of opinion exists as to whether steaming or hot-water heating is preferable. Steaming is favoured on the ground that it provides quicker heat transfer, and some operators cover the logs with sawdust during steaming. Heating in water is considered to be a milder treatment and more suitable for species which tend to crack when heated. The duration of softening treatment depends upon the species and the size of the log. It will usually be from 5 to 12 hours, and may be as long as 24 hours. Some species, such as Douglas fir, basswood, and white birch cut satisfactorily at room temperature without heat treatment. Yellow birch may be cut at temperatures as low as 140°F. and as high as 180°F (5).

End-checking sometimes develops as a result of heating. This checking is believed to be due to a combination of natural stresses present in the wood when it is cut, and the thermal expansion which

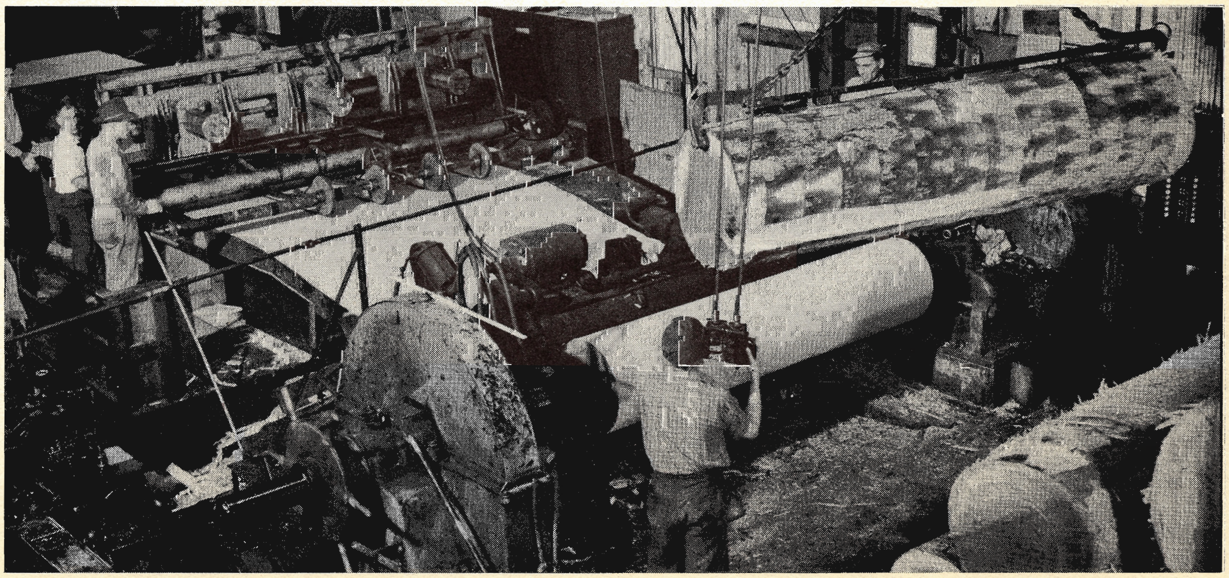


PLATE 90.—Veneer-cutting Lathe. Fresh log on hoist.

occurs as a result of heat treatment. Veneer logs which have a tendency to develop end-checks should, if possible, be heated in log lengths, and cut into bolts after heating. This method reduces waste by restricting the end-checking to the two exposed ends of the log. After the softening treatment, the logs are removed from the vats and the bark is removed with axes or chisel bars. In some plants, mechanical barkers which also rough-turn the log are employed to remove excess material from eccentric logs and from those with pronounced taper.

The logs are then lifted by means of a hoist, and lowered into the lathe until the ends are centred between the lathe chucks, which are driven into the log. The cutting mechanism is advanced to take the initial cut from the rotating log. Adjustable spur knives are mounted ahead of the lathe knife, to regulate the width of the cut and to remove doty wood, checks, and other defects which may be present at the ends of the log. The pressure bar compresses the wood ahead of the knife and thus reduces splitting and excessive cutting checks. Some lathes are equipped with a roller which functions in a similar manner to the pressure bar. The initial cut produces triangular-shaped pieces of veneer known as 'fish-tails', which result from the taper of the log. In some cases, these pieces are utilised in making small plywood panels, but they are frequently hogged into fuel. When the knife is cutting the full length of the log, it produces a more or less continuous sheet of veneer. In most softwood plants, a system of conveyor belts carries the veneer from the lathe to the clipper; the belts are arranged at different levels one above the other, and are filled in succession as the veneer comes off the lathe. In other plants, the veneer is fed on to a long table, broken by hand into sheets, and piled. This process is continued until the log has become so small that further peeling is not mechanically possible, or until the knots, cracks, checks, or other defects exposed render further peeling uneconomical. The sheets are transferred to a clipper and cut to size. Special clippers which remove defects and automatically cut the veneer to correct width are now being used. An alternative method frequently used is to wind the veneer around a drum or spool as it comes from the lathe. This reduces breakage and wastage, as the veneer can be handled more carefully and conveniently at the clipper and can be cut to width without the loss and de-grade occurring when the veneer is broken by hand as it comes from the lathe (6).

The core remaining is removed from the lathe and is utilized for fuel-wood or is sent to a sawmill for conversion into ties, pickets, crating stock, flooring, planks, or other products. In some plants, the cores from the larger lathes are sawn into half-lengths and are then re-cut on smaller lathes, producing veneers which are used for cores in plywood or for fruit containers.

Veneer lathes are available in a wide variety of sizes, depending upon the length of the knife, which ranges from 3 feet to over 12 feet, and upon the swing of the lathe, which determines the maximum diameter of log that can be cut: this may be as great as 110 inches.

The thicknesses of veneers made by rotary cutting are usually from one-fortieth to one-quarter inch, although special thicknesses outside this range can be cut from some species.

Rotary-cut veneer has a tendency to revert to its original curved shape, and when it is flattened compression occurs on the outside surface, or 'tight side', and tension on the inside surface, or 'loose side'. The resulting strain on the loose side during cutting may cause 'cutting cracks' or checks to develop, especially in the thicker veneers.

Lathe speeds vary according to the quality and thickness of the veneer being produced, and according to the method employed to handle the veneer as it comes off the lathe. Most lathes are equipped with some form of variable speed drive.

Half-round or Stay-log Cutting

Stay-log cutting is a modification of rotary cutting and is generally used to produce figured face veneers from stumps, burs, and crotches, or from species having a marked radial figure. The logs are cut through the heart to provide two or more flitches which are softened by steaming or hot-water heating, as for rotary cutting.

A stay-log is a heavy steel casting which is mounted on eccentric chucks in a conventional rotary lathe. The flitch is securely fastened to the stay-log in such a manner that radial, tangential, or other faces may be presented to the knife, depending upon which provides the best grain figure. The sheets of veneer are kept in sequence, and sold in the same manner as sliced veneer.

Slicing

This method of cutting veneer is usually employed for the production of figured veneers for fine panelling and cabinet-work. The angle of cut can be varied with respect to the grain of the wood, so as to bring out the most attractive grain figure. Successive sheets of sliced veneer are frequently matched to produce pleasing figure formations in plywood and furniture. Slicing is also used in the manufacture of plywood veneer from Sitka spruce, red pine, western red cedar, and yellow poplar.

Sliced veneers are usually cut from logs 12 to 16 feet long. These are first cut in half along the axis in order to permit examination of the grain of the wood. The log is then cut either into radial segments for slicing into the more attractive quartered veneers, or into rectangular pieces for plain-cut veneers.

Before the actual slicing begins, the segments are heated by steam or hot water, as for rotary cutting. This is even more important in slicing, because much of the figured wood is cut across the grain.

The vertical veneer slicer is the type most commonly used in North America. The flitch is firmly fastened by screw dogs to a heavy metal plate moving in slides. On the downward stroke the flitch is brought in contact with the pressure bar and knife. The sheet of veneer passes through a slot in the knife carriage similar to that on the rotary lathe. On the upstroke the knife carriage automatically moves forward and thus is in position to slice off another sheet with the next cutting stroke. The slides are set at an angle, so as to give the flitch a slight lateral movement as it passes across the knife, which improves the quality of the cut.

As each sheet from a flitch comes from the knife, it is turned over and piled in the same sequence as it is cut. This order is carefully maintained in subsequent drying and handling operations. The veneers from one flitch are usually sold as a unit.

The face veneers produced by slicing are usually 1/28-inch thick. It is interesting to note, however, that veneers as thin as 1/500 inch and as thick as ¼ inch have been produced by this method.

Sawing

Sawing is probably the oldest commercial method of producing veneer. Logs are cut into flitches similar to those used for slicing and are sawn without heat treatment. A special saw, called a segment saw, is used for sawing veneer. It consists of a heavy metal tapered flange to the periphery of which thin saw segments are bolted. The log to be sawn is firmly secured by bolts or clamps to a travelling carriage which carries the flitch horizontally against the saw. After each cut the flitch is moved towards the saw a distance governed by the thickness of the veneer.

Although the kerf of a segment saw is considerably less than that of a conventional circular saw, the process is still wasteful, particularly for thin veneers. With the development of modern veneer slicers, the production of sawn veneer is decreasing and this method is now used mainly for sawing veneers from very hard woods or those whose colour would be impaired by cooking or hot water heating.

Veneer Drying

Veneers cut by any process normally have a high moisture content, and must be dried as soon as possible to below 10 per cent in order to avoid attack by fungi and to make them suitable for gluing. The only exception is the veneer for the manufacture of fruit and berry baskets, which is used in the wet condition in order to facilitate bending and shaping operations.

Several different methods are used for drying veneer, depending on the nature of the veneer and the facilities available.

Air-drying—The cheaper grades of rotary-cut veneers used for fruit crates and packing-cases are frequently dried in the open. The sheets are laid between tiers of stickers, or are loosely stacked on end in finger-racks, in order to permit free circulation of air over their surfaces.

Loft-drying—This method is sometimes used for drying fragile figured veneer. A loft is a well-ventilated room which is maintained at a temperature between 90°F. and 100°F. and a relative humidity of 60 to 70 per cent. The wet sheets of veneer are hung by clips from rafters or overhead wires, or they may be edge-stacked in finger-racks. Only a day or two in the loft is required to bring the moisture content of veneers approximately 1/20 inch thick down to a moisture content of 12 to 15 per cent.

Kiln-drying—The conventional progressive dry kiln is also used for drying veneers. In this method the veneers are piled between stickers on kiln cars

which are moved forward through the kiln. Temperature and humidity conditions are graduated along the kiln so as to produce uniform drying.

Platen or Breather Drier

This type of drier consists of a number of steam-heated plates that automatically open and close at regular intervals. Sheets of veneer are placed between the open platens which, as they come together, press the veneer flat and convert the moisture into steam which escapes as the platens open. A more modern development is the progressive platen drier in which a series of moving rollers carry the veneer forward through successive platens each time the platens open.

Roller and Conveyor Driers

Most plywood veneers are dried in continuous veneer driers, which are long chambers equipped with rollers or wire belts to carry the veneer through the chamber. The entire heating chamber is enclosed to prevent loss of heat, and the air is kept in constant circulation across the heating coils and the veneers by powerful fans. These driers are available in different lengths and may have as many as six lines or decks. In order to utilize both sides of the rollers or belts, some driers are designed so that veneer can be fed in and discharged at each end of the drier. The rate at which the veneer moves through the drier is regulated according to such factors as the species of wood, the thickness of the veneer, the original moisture content, and the degree of dryness required (7).

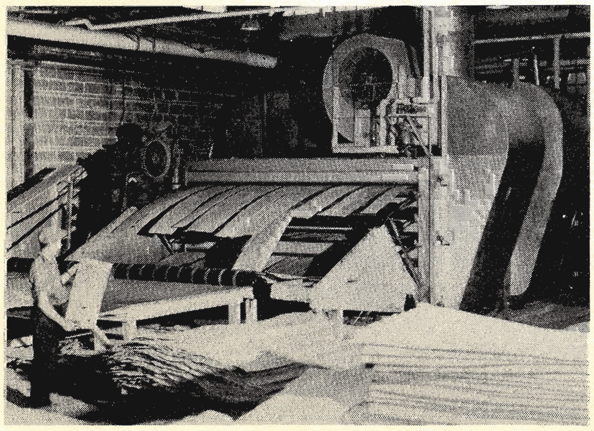


PLATE 91.—Veneer Leaving Dryer.

MANUFACTURE OF PLYWOOD

Preparation of Veneer

VENEER which is to be made into plywood is usually dried to a uniform moisture content of between 3 and 5 per cent. An exception is veneer bonded with cold-press urea resin. In this case the moisture content should be at least 6, and preferably 8 per cent. If the veneer is shipped to the plywood plant from a separate veneer mill, it is usually necessary to re-dry the veneer in a platen drier. Owing to clipping operations, which eliminate major defects, veneers are frequently cut into strips which are not wide enough for the face of finished plywood panels. In the better grades of commercial plywood, these narrow strips are edge-glued together to form sheets wide enough to make up complete faces or backs. This is done by first making a smooth straight edge on the veneers by means of a veneer-jointer. The sheets are then fastened together along the edges by means of a gummed paper tape or by a tapeless splicer. The first method uses a mechanical taping machine which has two feed rollers that force the edges of the veneers together while the paper tape is applied. During the plywood pressing operation some of the glue flows between the edges of the taped veneers and glues them firmly together. The tape can be removed from the plywood by sanding or wetting.

The tapeless splicer is coming into more general use. Tapeless splicing not only saves the cost of the tape, but also the cost of tape removal. The machine is equipped with a link-belt conveyor and a set of angled rollers which feed the veneer through the machine and also force the edges of the sheets together as the joint passes between two electrically heated strips. In one method the glue is applied to the edges of the veneers during the jointer operation. This glue becomes partly dried and is re-moistened by a suitable solvent which is applied by a thin disc as the veneers pass through the splicer. Alternatively, a special adhesive may be applied by the disc in advance of the heater strips.

Core veneers and cross-bands are not often edge-glued, but if they are taped the edges are clipped only and not jointed. The paper tape for the inner layers is generally permitted to remain in the panel. It is, however, perforated to allow the glue to pass through to the veneer and ensure a good joint between adjacent plies.

Veneers which contain small defects are often repaired by special equipment which cuts out the defect and glues in place a patch matching as closely as possible the grain and colour of the wood surrounding the defect. Figured face veneers are prepared in much the same manner as plain veneers, except that the more fragile types are flattened and dried by clamping between heated wooden boards. These veneers are frequently matched by combining successive sheets with a repetition of the grain figure in different patterns and geometrical forms. After the veneer edges have been trimmed to shape, the sheets are joined together either by taping or in a tapeless splicer.

Preparation of Lumber Cores

Lumber-core plywood is preferred by the furniture industry for many applications. The usual construction consists of a lumber core five-eighths to three-quarters of an inch thick, two cross-bands 1/20-inch thick, and face and back veneers 1/28-inch thick. Since the lumber core contributes most of the strength to the panel, it must be carefully prepared. Essentially, the core consists of sawn lumber strips which are edge-glued. The wood must be well seasoned to a uniform moisture content between 5 and 8 per cent, and should be free from stress. The lumber is first cut to length and surfaced on one or both sides, and is then ripped into strips clear of defects and not wider than three inches. For gluing, the edges of the strips may be jointed, tongue-and-grooved, or rip-sawn, the latter being satisfactory for most purposes. The strips are laid up into panels with their grain alternated in such a manner as to balance stresses caused by changes in moisture content.

The edges of the core-strips are spread with an animal or a cold-setting resin glue and reassembled into panels for pressing. Usually the core-strips

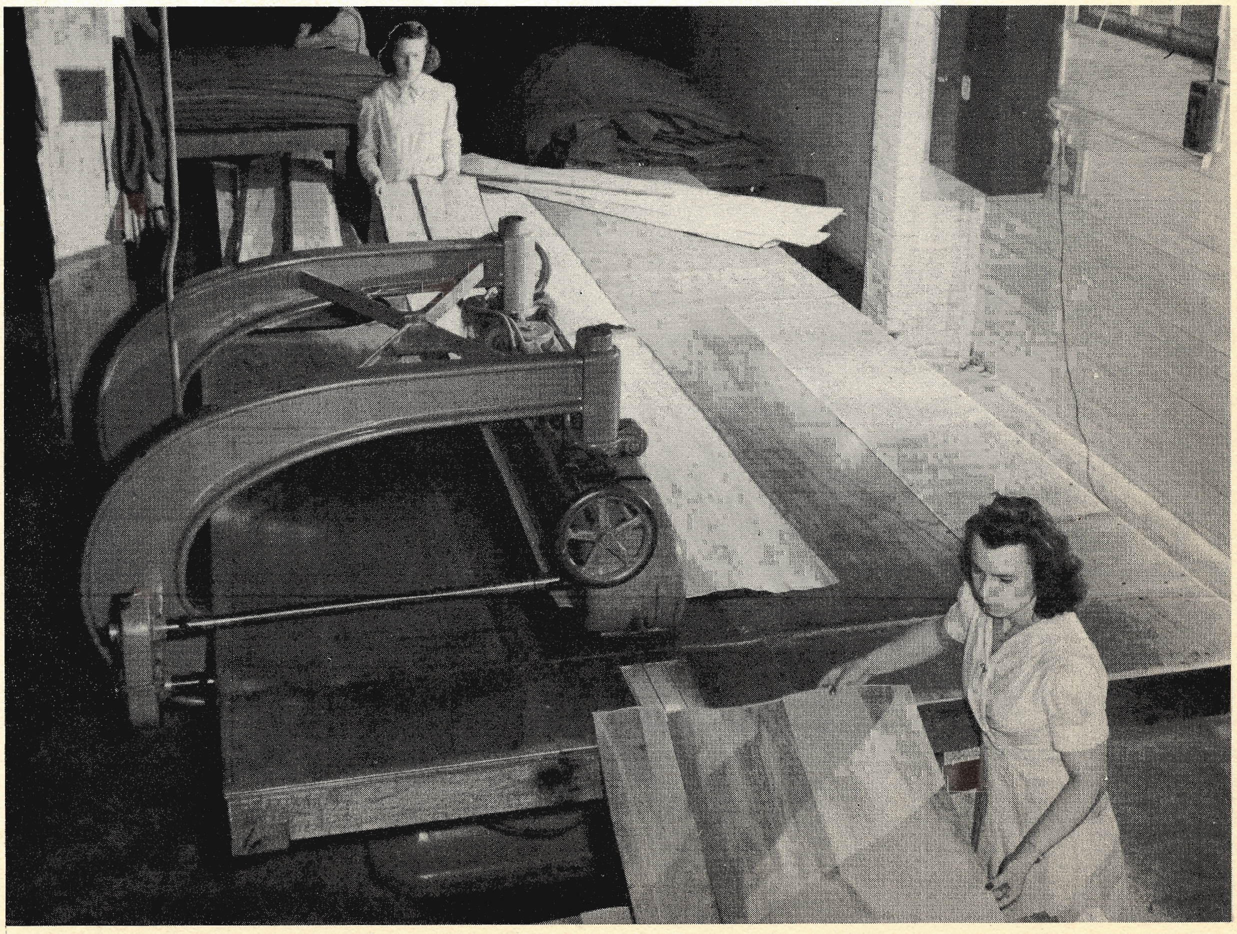


Plate 92.—Edge-gluing in Tapeless Veneer Splicer.

are edge-glued in a revolving clamp carrier; this machine consists of a series of double clamps which are mounted like the spokes of a wheel on an endless belt. As each core panel is laid up in the clamp, it is tightened and moved forward, the next empty clamp coming into position to receive another panel. The panels remain in the clamps until the glue dries or cures. Another method of gluing core material employs an automatic machine in which a number of glued strips are passed between heated plates where the glue is cured in a few minutes. A more recent development is the application of dielectric heating for rapidly curing the glue lines of core-stock (see page 271).

After edge-gluing, the core panels are trimmed and in some cases strips of wood called bands or rails, of the same species as the face veneer of the finished plywood, are glued around the edges. The panels are then dressed to provide a smooth gluing surface for the cross-bands (8).

Plywood Gluing

The type of glue used in the manufacture of plywood depends upon the purpose for which the plywood is intended. In the case of box plywood, inexpensive starch glues or silicate of soda are adequate for most purposes. Plywood designed for permanent interior service is usually bonded with moisture-resistant glues, such as casein, soya-bean, blood albumen, and extended urea-formaldehyde resin. Phenol-formaldehyde glue, in either liquid or film form, is used for plywood which is to be exposed to severe conditions of moisture and humidity, as in marine and outdoor applications.

When the various components of plywood—the faces, backs, cross-bands, and cores—have been prepared and conditioned to the correct moisture content for the glue used, they are assembled on trucks near a mechanical glue-spreader. This machine consists of two grooved rollers of steel or rubber placed one above the other, to which a predetermined spread of glue is fed by doctor-rollers. The veneer is fed into the machine and the rollers carry the veneer forward and spread glue on one or both faces as required. It is usual practice to apply glue to both sides of the core only in three-ply and to both sides of the cross-bands only in five-ply construction. In multi-ply construction, each alternate ply is glued on both sides. In some cases of double-spreading, the face plies are placed face to face and passed through the spreader in pairs so that one face only of each ply is spread. After glue spreading the veneers are assembled in proper sequence ready for pressing.

Cold-pressing

Plywood made with cold-setting adhesives such as casein, starch, vegetable protein, silicate of soda, and cold-setting resin glues may be stacked in bundles and pressed in a screw or hydraulic press without the application of heat. Pressures between 75 and 150 pounds per square inch are usually employed in cold-pressing, but, in the case of cold-setting resin glues, pressures between 100-250 pounds per square inch are required. It is important that some means be provided to maintain pressure on the plywood until the glue is set. This is usually accomplished by clamping the bundle between I-beams equipped with screwed rods fitted with clips and turn-buckles. The clips engage the flanges of the I-beams and the turn-buckles are tightened when full pressure has been applied. The pressure is then released and the clamped bundle removed and stored till the glue has set—usually from 4 to 16 hours—after which time the clamps are removed. When a vegetable or casein glue is used, it is important that the plywood be re-dried after pressing in order to remove the surplus water introduced by the glue mixture. This is usually done by piling the plywood on successive layers of narrow sticks immediately after it is removed from the clamped bundles. The stacks are placed under weights and stored in a heated room or kiln equipped with forced-draught circulation. The temperature in the re-dryer is usually between 110° and 120°F. with relative humidity of 50 to 60 per cent.

Hot-pressing

In the hot-press method, the plywood assemblies are pressed between heated plates. This is the method in general use for the production of plywood bonded with hot-setting resin glues. Special presses which contain from 5 to 25 steam-heated plates have been developed for the production of hot-press plywood. When the press is opened, these plates are separated at regular intervals. The veneers for hot-pressed plywood are prepared and assembled in much the same manner as for cold-pressing and are placed between the heated plates. When all the openings have been filled, the press is closed as rapidly as possible, the plates coming together progressive-

ly from the bottom, and full pressure is applied. Pressures used in hot-pressing range from 150 to 250 pounds per square inch, the higher being used for the denser woods. Mechanical loaders are frequently used in conjunction with the larger hot presses in order to transfer the plywood lay-ups into the press in the shortest possible time, otherwise the glue may partially cure before full pressure can be applied. To slow up heat transfer during the loading operation, wood or metal cauls are usually placed on both sides of the plywood assemblies before loading the press (9). These serve as temporary heat insulators and also assist in handling the veneers during loading.

The time required to cure the glue by the hot-press method will vary from two to twenty minutes, depending upon the thickness of the stock, the distance of the glue-line farthest removed from the plate, the type of glue, and the plate temperature. Time and temperature schedules for hot-pressing are provided by the various glue manufacturers (10, 11).

During the hot-pressing operation, the temperature of the wood is raised above the boiling point of water and consequently the plywood dries rapidly on removal from the hot press. This condition sets up stresses which may cause warping or surface checks (12). In order to restore the normal moisture content to the plywood, the panels taken from the press are usually sprayed, sponged, or quickly dipped in a vat of water, and then piled, either solid or between stickers, under weights until the moisture has been re-distributed. If the face panels have been taped, the tape can be conveniently removed directly after the water treatment.

After plywood has been properly re-conditioned, it is trimmed to dimensions and squared on double cut-off saws. If required, sanding is next done on multiple-drum-sanders. The panels are then graded, and prepared for shipment.

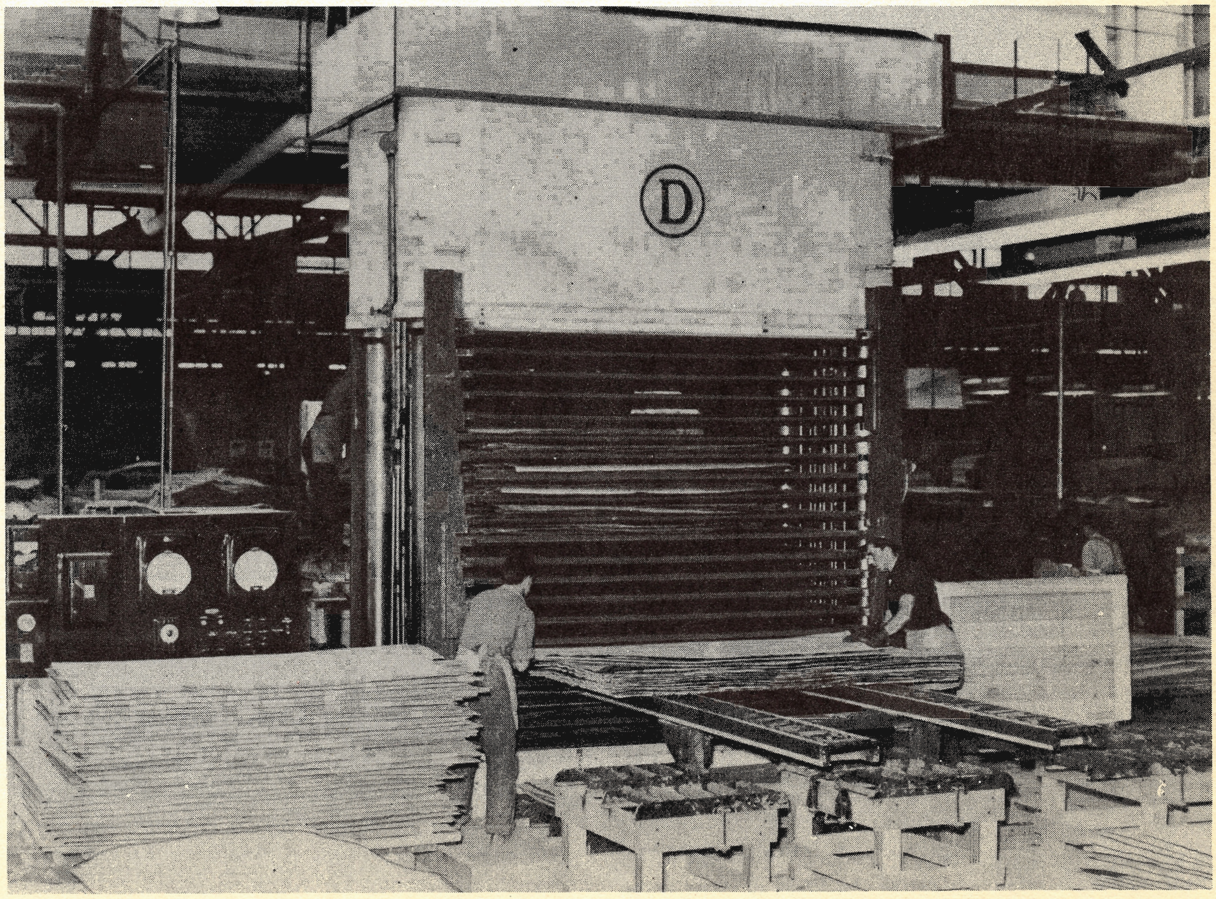


PLATE 93.—Loading Plywood Hot Press.

STANDARD PLYWOOD CONSTRUCTION AND GRADES

Softwood Plywood

DOUGLAS fir plywood is manufactured and graded in accordance with a standard issued by the Plywood Manufacturers' Association of British Columbia. This standard at present provides for two basic types of Douglas fir plywood, an exterior type bonded with a fully waterproof phenolic adhesive, and an interior type bonded with a moisture-resistant adhesive. Each type is manufactured in several appearance grades according to the quality of the veneer used for the face and back. The standard also describes the performance tests which each type must be capable of passing. The standard

TABLE 31

STANDARD DOUGLAS FIR PLYWOOD SIZES

ITEM	WIDTH		LENGTH	THICKNESS*	
Interior Type					
	INCHES			INCHES	
A-A (Sound 2 Sides - Int.) A-B (Sound/Solid - Int.) A-D (Sound 1 Side - Int.) B-D (Solid 1 Side - Int.)	30 36 42 48 48 48 48	× × × × × × ×	60 72 84 96 108 120 144	3/16 1/4 3/8 1/2 5/8 3/4	(3-ply; sanded 2 sides) (3-ply; sanded 2 sides) (3-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides)
C-D (Sheathing - Int.)	48 48 48 48	× × × ×	96 108 120 144	5/16 3/8 1/2 5/8	(3-ply; unsanded) (3-ply; unsanded) (5-ply; unsanded) (5-ply; unsanded)
B-B (Concrete Form panels - Int.)	48	×	96	1/4 1/2 9/16 5/8 3/4	(3-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides)
Exterior Type					
A-A (Sound 2 Sides - Ext.) A-B (Sound/Solid - Ext.) A-C (Sound 1 Side - Ext.) B-C (Solid 1 Side - Ext.)	30 36 42 48 48 48 48	× × × × × × ×	60 72 84 96 108 120 144	3/16 1/4 3/8 1/2 5/8 3/4 7/8 1 1 1/8	(3-ply; sanded 2 sides) (3-ply; sanded 2 sides) (3-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides) (5-ply; sanded 2 sides) (7-ply; sanded 2 sides) (7-ply; sanded 2 sides) (7-ply; sanded 2 sides)
C-C (Sheathing - Ext.)	48 48 48 48	× × × ×	96 108 120 144	5/16 3/8 1/2 5/8	(3-ply; unsanded) (3-ply; unsanded) (5-ply; unsanded) (5-ply; unsanded)
B-B (Concrete Form panels - Ext.)	48	×	96	5/8 3/4	(5-ply; sanded 2 sides) (5-ply; sanded 2 sides)

*Number of plies is minimum.

sizes in which Douglas fir plywood is made are given in Table 31. A tolerance of 1–64 inch over or under the specified thickness is allowed on sanded panels and a tolerance of 1/32 inch on unsanded panels. A tolerance of 1/32 inch over or under the specified length and width is allowed, but all panels must be square within one-eighth inch. Table 32 shows the nominal veneer thickness and weight of different types of plywood manufactured from Douglas fir.

Hardwood Plywood

In Canada, hardwood veneer and plywood are graded in accordance with a standard issued by the Canadian Hardwood Veneer and Plywood Association. This standard provides for two types of hardwood plywood, Interior (Int.), and Exterior (Ext.),

TABLE 32

NOMINAL VENEER THICKNESSES AND WEIGHTS OF DOUGLAS FIR PLYWOOD

Plywood Thickness (Net)	No. of Plies	Veneer Thickness (Nominal) in Inches			Weight lbs. per 1000 sq. ft., approx. (As shipped from mill)
		Faces*	Centers	Crossband	
1/8 "—R	3	1/24	1/24		490
1/8 "—S	3	1/16	1/16		490
3/16"—R	3	1/16	1/16		640
3/16"—S	3	1/12	1/12		640
1/4 "—R	3	1/12	1/12		790
1/4 "—S	3	1/9	1/9		790
5/16"—R	3	$1/10^{+}$	$1/10^{+}$		950
5/16"—S	3	1/8	1/8		950
3/8 "—R	3	1/8	1/8		1125
3/8 "—S	3	1/8	3/16		1125
3/8 "—S	5	1/10	1/12	2 at 1/12	1125
7/16"—R	3	1/8	3/16		1300
7/16"—R	5	1/10	1/12	2 at 1/12	1300
7/16"—S	5	1/10	1/10	2 at 1/10	1300
1/2 "—R	5	1/10	1/10	2 at 1/10	1525
1/2 "—S	5	1/8	1/8	2 at 1/10	1525
9/16"—R	5	1/8	1/8	2 at 1/10	1675
9/16"—S	5	1/8	1/8	2 at 1/8	1675
5/8 "—R	5	1/8	1/8	2 at 1/8	1825
5/8 "—S	5	1/8	3/16	2 at 1/8	1825
11/16"—R	5	1/8	3/16	2 at 1/8	2000
11/16"—S	5	1/8	1/8	2 at 3/16	2000
3/4 "—R	5	1/8	1/8	2 at 3/16	2225
3/4 "—S	5	1/8	3/16	2 at 3/16	2225
3/4 "—S	7	1/8	2 at 1/12	3 at 1/8	2225
13/16"—R	5	1/8	3/16	2 at 3/16	2375
13/16"—R	7	1/8	2 at 1/12	3 at 1/8	2375
13/16"—S	7	1/8	2 at 1/8	3 at 1/8	2375
7/8 "—R	7	1/8	2 at 1/8	3 at 1/8	2600
7/8 "—S	7	1/8	2 at 5/32	3 at 1/8	2600
15/16"—R	7	1/8	2 at 5/32	3 at 1/8	2800
15/16"—S	7	1/8	2 at 3/16	3 at 1/8	2800
1 "—R	7	1/8	2 at 3/16	3 at 1/8	3000
1 "—S	7	1/8	2 at 1/8	3 at 3/16	3000
1 1/16"—R	7	1/8	2 at 1/8	3 at 3/16	3175
1 1/16"—S	7	1/8	2 at 1/6	3 at 3/16	3175
1 1/8 "—R	7	1/8	2 at 1/6	3 at 3/16	3350
1 1/8 "—S	7	1/8	2 at 3/16	3 at 3/16	3350
1 3/16"—R	7	1/8	2 at 3/16	3 at 3/16	3525
1 3/16"—S	7	1/8	2 at 7/32	3 at 3/16	3525

S — Sanded R — Rough

*For sanded panels, thickness is before sanding, Data from Douglas Fir Plywood Association publication "Technical Data on Plywood."

the type referring to the moisture-resistance of the adhesive used. Interior-type hardwood plywood is bonded with a water-resistant adhesive, and is suitable for applications where there may be occasional exposure to moisture. The glue bond in interior type plywood must be of such a quality that specimens will withstand the cold soak test described in the standard. Exterior type hardwood plywood is bonded with a fully waterproof adhesive and is suitable for marine and permanent exterior use. The glue bond in exterior type plywood must be of such a quality that specimens will withstand the boil tests described in the standard.

Within each type of hardwood plywood there are several grades which are established by the quality of the veneer in the plywood. Four grades of veneer quality, A, 1, 2, and 3, are defined in the standard. Plywood is designated according to its type and the grade of veneer used for its face and back plies. For example, a panel designated Int. A-3 would be bonded with a water-resistant adhesive and would have a grade A face veneer and a grade 3 back veneer.

PLYWOOD TESTING

THE strength and durability of plywood glue bonds may be tested by means of a plywood glue shear test. Material for test specimens should be taken at random from a larger panel. The test specimens are prepared 1 inch wide, 3¼ inches long, and 3 plies thick. Two grooves one-eighth inch wide and spaced 1 inch apart are cut two-thirds through the core from opposite faces, as shown on page 270. Plywood consisting of more than three plies is stripped of all except any three selected plies. The ends of the specimens are gripped by jaws in a testing machine and a tension load is applied at a rate of 600 to 1,000 pounds per minute until separation takes place. Maximum load and the percentage wood failure are recorded. The specimens may be tested dry at a moisture content of from 8 to 12 per cent, or they may be tested after a soaking or boiling treatment designed to determine the durability of the adhesive (13, 14).

Methods for determining mechanical and physical properties of plywood are described in American Society for Testing Materials Standard D. 805-47, "Standard Methods of Testing Plywood, Veneer, and Other Wood and Wood-Base Materials".

SPECIAL PLYWOOD PRODUCTS

PANELS possessing special characteristics and properties can be made by combining veneer or plywood with other materials such as metal, paper, resin-impregnated paper, fabrics, and fibreboards.

Metal-faced plywood is prepared by bonding sheets of metal to one or both sides of plywood. The resulting combination of metal and plywood makes an exceedingly stiff panel with a hard, durable surface. Almost any metal in any thickness can be bonded to plywood. In cold-pressing, the most common glues for bonding metal to wood are combinations of casein and latex. These glues cure at room temperature, they are water-resistant, and are sufficiently elastic to withstand stresses caused by thermal expansion of the metal. The edges of the panel are usually sealed by folding the facing material over the plywood. Metal-faced plywood is also made by the hot-press process, using glues consisting essentially of rubber and resin. The unique properties of metal-faced plywood make it suited for use in the construction of truck bodies, stream-lined trains, elevator cabs, buses, and for many uses where neither metal nor plywood would be adequate by itself.

In addition to its use as a facing material, the metal sheet may form an inner layer of the plywood. This construction is employed in panels for fire-resistant walls and cigarette-proof desk tops. For applications which require the beauty of wood combined with the structural characteristics of sheet metal, thin figured veneers are bonded to sheet metal (15).

The appearance and working characteristics of plywood are improved when it is faced with sheets of resin-impregnated paper. Overlays of paper improve the strength of plywood and they provide a smooth, uniform surface for finishing operations. The paper also conceals minor plywood defects and eliminates problems of grain-raising and surface-checking. Paper-faced plywood has been used as concrete form material and in house construction (16).

Decorative laminated plastic sheets are frequently used to face plywood tops of tables, counters, and sinks. These sheets can be bonded to the plywood with either a casein or a cold-setting phenol-resorcinol resin glue. The latter type of adhesive should be employed where high moisture resistance is desirable, as in the case of sink units. To facilitate gluing, the back of the sheet should be suitably

PLATE 94.—Applications of Veneer and Plywood.

roughened. If the plastic laminate is glued to one side only of the top, the plywood base should be of sufficient thickness to resist possible warping due to the unbalanced construction.

A strong, light panel is made by bonding kraft paper to both sides of veneer. The grain of the paper is laid at right angles to the grain of the core veneer. Paper-faced veneer is used for furniture backs, radio backs, displays, and shipping containers (17).

Thin sheets of veneer bonded to a fabric backing provide a flexible decorative material which can be applied to walls, ceilings, and columns in much the same manner as wall-paper.

Plywood is frequently employed as the facing skin for lightweight sandwich constructions used in aircraft. In these constructions, the plywood is glued to both sides of a low-density core consisting of balsa wood, formed plastics, or a built-up honeycomb.

Various other combinations of veneer and plywood with materials such as fibreboard, hardboard, plastics, and asbestos are made to meet special requirements.

Curved and Moulded Plywood

Curved plywood panels are made either by bending flat plywood or by forming the veneers during the gluing operation.

Thin plywood can be bent to moderate curves in the dry condition and to more pronounced curves by passing it between the hot rollers of a plywood bending machine. Curved panels are also made by soaking or steaming thin plywood sheets which are bonded with a waterproof resin glue. A common method of bending thick plywood is to make a series of equally spaced saw-cuts from the back side of the panel through the core to the cross-band veneer. Removal of wood by these cuts allows the panel to be bent. Frequently the inner portion of the curved section is reinforced by gluing on a strip of veneer.

Curved plywood made by forming the veneers during the gluing operation has the advantage of being free from stress. In one process, the veneers are spread with glue and are bent to shape between a pair of forms or dies. Hot-pressed curved plywood can be made by heating the dies either with steam or with electrical heating elements; laminated barrel staves also are made by this method (18). A recent development is the use of dielectric heating to accelerate the curing of the glue in curved plywood panels. Alternatively, curved plywood may be produced by a bag-moulding process. In this process, the veneers are coated with a glue which will cure at room temperatures and are placed on a male form inside an air-tight flexible bag. When the air is exhausted from the bag by a vacuum pump, the bag exerts a pressure which bends the veneer to shape around the male form. This process is also used for applying veneer to curved sections of solid wood.

Curved plywood for drawer fronts is often made with curved lumber cores band-sawed from glued-up blocks. The face veneers and cross-bands are spread with glue and then assembled with the core; the assemblies are then stacked and kept under pressure until the glue has cured.

In the construction of moulded plywood boat hulls and aircraft fuselages, where the plywood is in compound curvature, that is, curved in more than one direction, a special bag-moulding process is employed. This involves the preparation of either a male or female mould. Strips of veneer are cut to shape and are coated on one side with a hot-setting resin glue which is allowed to dry but is not cured. The veneer strips are then laid up in successive layers on the form in such a manner that an unglued face is next to the form and on the outside of the lay-up; the mould and veneers are inserted into a flexible bag which is placed in an autoclave with an outlet from the interior of the bag either to a vacuum pump or merely vented to room atmosphere. Steam and air are introduced into the autoclave to force the veneers against the mould and to apply the heat necessary to cure the glue (19,20).

USES OF PLYWOOD

PLYWOOD is an adaptable material which is being used for a wide and ever-increasing diversity of applications. The following is a brief summary of some of the more important examples of plywood utilization.

Furniture and Allied Products

The furniture and allied industries require large amounts of plywood in the manufacture of such products as tables, dressers, bureaus, buffets, sideboards, bedsteads, desks, pianos, and radio cabinets.

Lumber-core plywood faced with figured veneers is usually employed for tops, ends, doors, and drawer fronts, while thin plywood is used for drawer-

bottoms, mirror-backs and case-backs. The lumber-core plywood is normally of five-ply construction, and in the better grades of furniture the edges of the cores are banded to conceal end-grain and to allow the edges to be moulded. Furniture made of lumber-core plywood is not only more dimensionally stable than that made of solid lumber, but the use of plywood facilitates economical use of the more attractive woods.

In some furniture, the ends and doors are made by gluing thin plywood to one or both sides of a solid wood frame. This type of construction is cheaper than lumber-core plywood and, for many types of furniture, is perfectly satisfactory. Curved plywood panels for furniture are usually prepared by bending flat plywood, as mentioned previously.

Building Construction

The strength and decorative qualities of plywood, and its availability in sheets of standard size, make it an ideal material for architectural and building purposes.

Where used for panelling interior walls, plywood may serve only as a surface decoration or it may also form an essential part of the structure. Plywood with figured veneers is preferable for walls which receive a natural finish. The joints between panels may be butted, V-grooved, or covered with a moulding. In cases where the walls are to be finished with paint, enamel, or wallpaper, plywood with one sound face is generally used.

As a sheathing material, plywood makes a strong, stiff, and draught-resistant wall, and less labour is required for its application. An unsanded sheathing grade is suitable for covering walls and roofs. Plywood sheathing 5–16″ thick, when applied to studs or rafters on 16-inch centres, should be secured with common nails not less than 1¾ inches long, spaced 6 inches apart at all edges, and 12 inches apart at other bearing points (21).

Softwood plywood is used extensively for concrete form work. This plywood is cleaned and re-used for forms or, in some cases, for sub-flooring. When nailed to joists on 16-inch centres, a sub-floor of ½-inch Douglas fir plywood will support a uniformly distributed load of 100 pounds per square foot with a deflection of not more than 1/360 of the span.

Plywood with a waterproof bond is used extensively for exterior siding. Some softwood plywood has a tendency to develop surface checks when exposed to the elements and should be well protected with at least three coats of high-quality exterior paint.

A considerable quantity of plywood is used in the construction of kitchen cabinets, cupboards, and the built-in-furniture found in some modern homes. Hardwood plywood is being utilized to some extent as flooring.

Flush Doors

Large amounts of both softwood and hardwood plywood are used for the faces of flush doors. In some flush doors a solid core made of small wood blocks glued together is used; in others, the core is hollow, consisting of a lattice-work construction of wood, fibreboard, or fire-resistant material which is framed by rails and stiles of solid lumber. The plywood panels, either 2-ply or 3-ply, are glued to both sides of the core.

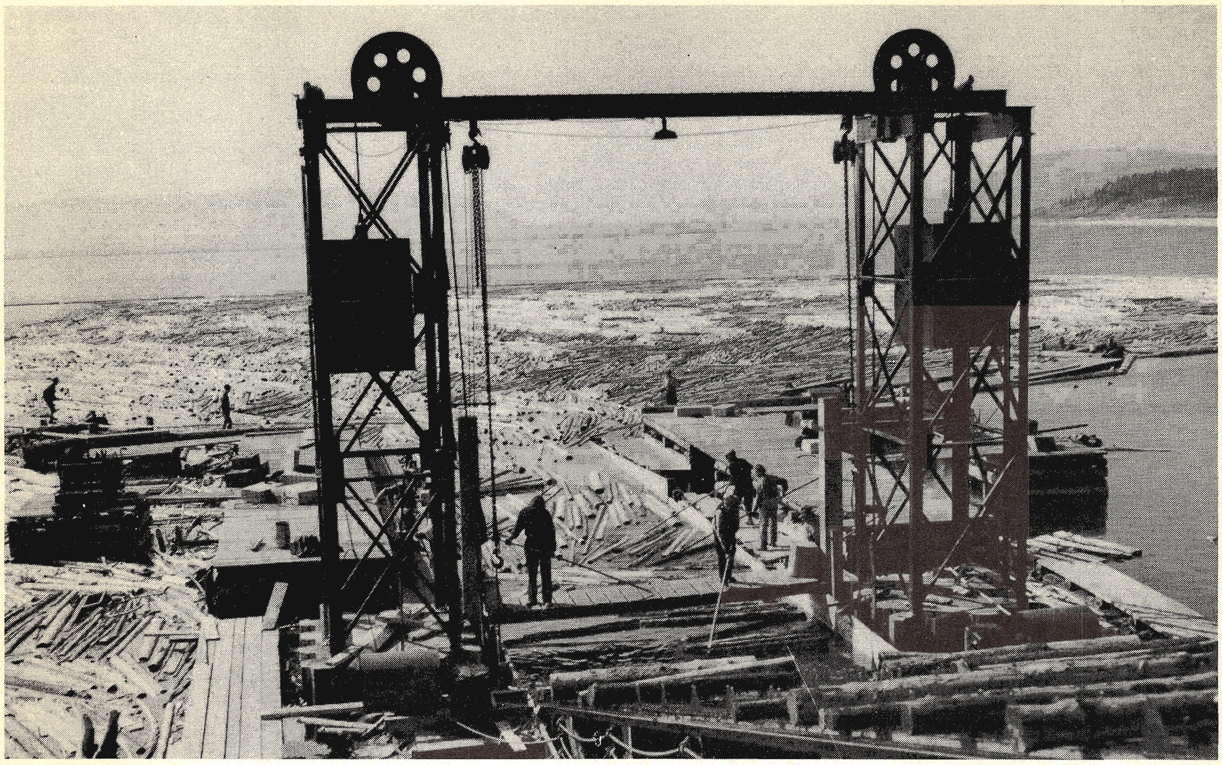
Prefabrication

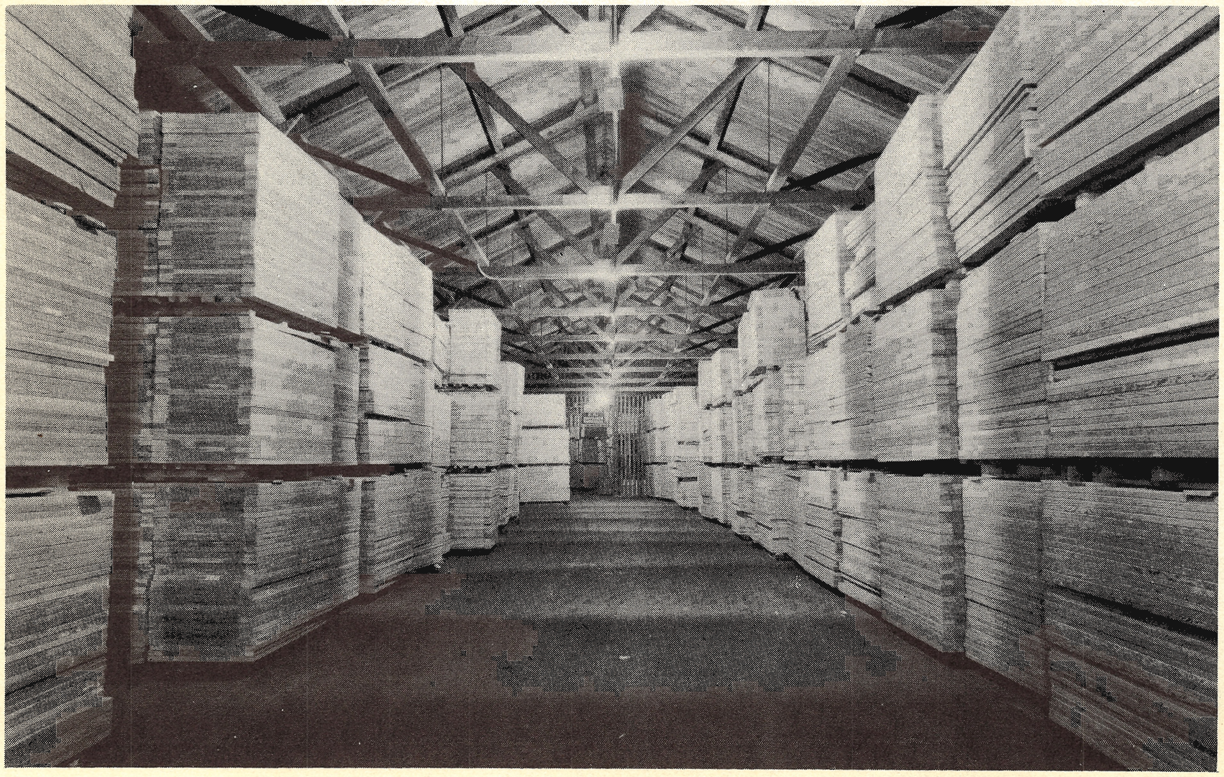
The advantages of plywood as a construction material are well exemplified in the field of prefabricated houses. The panels for these houses are generally factory-made and consist of standard sheets of plywood firmly glued to frame members. The plywood acts as a stressed skin and bears a substantial proportion of the working load imposed upon the panel. This type of construction provides maximum strength and rigidity with a minimum of materials (22, 23).

Vehicles

Plywood is an important raw material in the construction of commercial vehicles. Douglas fir plywood has been used extensively for the interior linings of freight cars and in some cases plywood of a waterproof grade is employed for the exterior siding. Freight cars built of plywood are lighter and cleaner than those made of matched lumber and less labour and time is required for their construction (24). Plywood is also used for the interior decoration of railroad passenger cars.

In other transportation fields, plywood is utilized for the production of bodies of trucks, buses, and trailers. The development of metal-faced plywood has further increased the usefulness of plywood for these applications.





Raw Material and Finished Product.

Boat-building

Plywood has been used for many years in the interior furnishings of the larger boats. The development of waterproof resin glues has greatly increased the value of plywood as a boat-building material (25). Sheets of waterproof plywood are being utilized to an increasing extent to plank the hulls and decks of lighter craft. As a planking material, plywood will cover large flat or slightly curved areas with few joints, and it has the further advantages of less tendency to split, improved screw-holding quality, and almost negligible shrinking and swelling. Strips of plywood can be scarf-jointed to obtain sufficient lengths for the larger hulls. The exposed edges of plywood planking should be sealed to prevent moisture absorption. Waterproof plywood is also used for the construction of superstructures and bulkheads on small boats.

The use of flat plywood for planking is limited to hull designs which do not involve double curvature. The fabrication of rounded plywood hulls of small boats has been made possible through the development of bag-moulding techniques. Streamlined moulded cabins for pleasure boats are also being made by this method.

Aircraft

Extensive use has been made of both flat and moulded plywood for the construction of aircraft, particularly in war-time. Employed as a skin covering for the fuselage and wings of aircraft, plywood offers the advantages of high strength and rigidity, combined with lightness. Plywood skins have no rivets to offer resistance to wind, they are not easily dented, and are not subject to electrolytic action. Thin sheets of plywood made of high-grade veneer may be employed for covering flat or moderately curved sections, while moulded plywood made by a bag-moulding process has been used for curved fuselage coverings. In positions subjected to torsional stress the direction of the plies is often placed at an angle between 45° and 60° to the edges of the sheet (26).

In addition to its application as a covering, plywood, because of its lightness and strength, is favoured in the fabrication of other aircraft parts and fixtures, such as ribs, gussets, floor boards, pilot seats, chart tables, and doors. The value of plywood for aircraft construction has been further increased through the use of sandwich constructions, in which plywood is employed as the facing material of a low-density core material.

A further use of commercial plywood is for the construction of full-size models of new aircraft designs.

Containers

The high strength and light weight of plywood make it an ideal material for the construction of containers. Plywood boxes are light in weight, easy to assemble, strong, rigid, and able to withstand severe blows without damage. They have a high percentage of usable volume and may often be re-used.

A considerable amount of box-grade hardwood plywood is manufactured in the eastern part of Canada. It is usually 3-ply, made of rotary-cut veneers of the same thickness, and is bonded with a vegetable glue. The veneers are not trimmed or taped, but after the glue is spread are laid up edge to edge and cold-pressed. The best veneers are selected for the faces, the second best for the backs and the remainder for the cores. The plywood is then trimmed and made up into panels by nailing strips or cleats of solid lumber along the edges and at intermediate points. The cleats, which are usually sawmill edgings, are gang-nailed to the plywood by means of automatic nailing machines. The cleats allow the shooks to be assembled into packing cases with nails at the corners. This type of container is used for shipping textiles, refrigerators, radios and similar products.

Softwood plywood bonded with resin glues is used to make more durable export containers for heavy machinery and automobiles (27). Tobacco hogsheads, which are used to store and ship tobacco, are being made from softwood plywood which has been bonded with a fully waterproof resin glue. Plywood, particularly basswood, is also used as the core material of fabric-covered luggage; it is bent to shape on plywood bending machines.

Miscellaneous

Other important uses for plywood include displays, signs, sporting goods, patterns, toys and games, musical instruments, chutes and bins, burial caskets, telephone and telegraph equipment, tool handles, toilet seats, trays, etc.

GLUES AND GLUING

by E. G. BERGIN

THE woodworker now has a wide choice of adhesives from which he may select the particular type which will best meet his requirements. Although still widely used, animal glues are being gradually displaced by other adhesives, chiefly the synthetic resins. This is also true of the protein glues, such as the casein and the soy-bean types. It should not, however, be inferred that the animal and protein glues are entirely obsolete, and that they will be in due course completely replaced by the synthetic resins: each type has specific advantages for certain applications.

Animal Glues

The animal glues consist of the gelatinous material extracted from the skins, bones, and fleshings of animals, and from fish offal. The process of extraction is repeated as often as may be necessary to remove all gelatinous constituents, the better grades of glue, having high jelly strength and viscosity, being derived from the earlier 'cooks'. The glue is prepared for use by the addition of water, the proportions depending primarily upon the grade of the glue (28). After determining the proper glue-to-water ratio, the mixture is allowed to soak for at least 6 hours. It is then heated in a water-jacketed glue-pot. The temperature of the pot should be controlled within a range of 140°F. to 150°F. Prolonged heating of glue solutions causes breakdown of the glue and reduces its adhesive properties (28). Cleanliness is very necessary in the glue-room. Left-over glue should be discarded at the end of the day and the pots, brushes, spreader, and other equipment should be thoroughly scoured with boiling water, otherwise bacterial activity may cause trouble.

The pressure applied to the glued assembly depends upon (a) the physical properties of the glue (the higher the viscosity of the glue, the higher the pressure required), (b) the characteristics of the wood species, (c) factors which are likely to cause rapid jelling, such as the time occupied in assembling the joint, the temperature of the wood, and that of the glue room, and (d) the moisture content of the wood. Similarly, the time the work is left in the clamps depends upon the time required for the glue to set and harden. Ordinarily, assemblies should remain under pressure for a period of six hours. In some cases, however (where little moisture is present in the wood and where a glue of high viscosity is being used), the time may be as short as one hour.

Animal glues come in various grades. For cabinetwork, it is considered more economical to use the best grade available, as varying the amount of water will produce glues suitable for various applications. These glues are not water-resistant, and should therefore be used only where the finished article will not be subjected to conditions of high humidity. They produce joints having excellent dry strength, and are economical in use.

Sanding operations on finished work should never be attempted until the wood has been properly conditioned. Seasoned wood in contact with moisture swells, but on drying to its original moisture content returns to its original dimensions. When animal, vegetable, casein, or other types of glue in which water is the vehicle are used, the water will be absorbed by the wood and will cause it to swell. If the wood is sanded before it has had sufficient time to lose this added moisture, the wood surface in proximity to the glue-line, which is slightly raised, will be sanded off and, upon shrinking back to its normal dimensions as it dries, it will be slightly lower than areas more remote from the glue line, causing what is commonly known as a "sunken joint".

Vegetable Glues

There are two types of vegetable glue—the starch type, derived from cereals, potatoes, or the root of the cassava (tapioca plant), and the protein type, derived from certain legumes.

Starch glue is prepared by adding to the dry starch 3 to 4 parts of water per unit of weight. The conversion into an adhesive is achieved by one of the following methods:
(a) by heating the starch suspension for approximately 1 hour at 150°F., (b) by adding 5 to 10 per cent caustic soda, without heating (c) by adding 3 to 5 per cent caustic soda and heating to 150°F. Of these methods, the last is preferred (29). Starch glues are very viscous, necessitating the use of mechanical spreaders. Because of their lack of water-resistance, the time they require to set, and their tendency to stain certain light-coloured woods, their usefulness is restricted. However, they have the advantage of cheapness, long assembly time, and long working

life. They are used chiefly in the manufacture of veneered products such as furniture and the cheaper grades of plywood, where water-resistance is not important.

The protein type is prepared mainly from soybean meal from which the oil has been extracted, and from certain other legumes. They are similar in formulation and character to the casein cements, being prepared by adding water, hydrated lime, and an alkali. Unlike the starch glues, they are always prepared cold. These adhesives are highly alkaline and tend to stain wood. They have the advantage of being fairly water-resistant and are inexpensive.

Casein Glues

Casein glues are generally supplied to the woodworker as a dry powder which is essentially a mixture of casein (from skimmed milk), hydrated lime, and other chemicals. The glue is prepared for use by the addition of 1 to 2 parts water per unit weight of dry powder. The "pot-life" of high-grade casein glue is between 6 and 8 hours, and assembly periods (the time between the gluing and closing of the joint) may vary from 15 to 45 minutes. Clamping periods are similar to those for animal glues. These adhesives are considerably more water-resistant than the animal or starch glues, and may therefore be used for a greater variety of applications. Because of their alkalinity, they facilitate the gluing of certain oily woods such as teak, pitch pine, or yew, and produce good joints between hardwoods. They have also been found satisfactory for the gluing of asbestos, compregnated and impregnated wood, plastic laminates, and tile and linoleum floor coverings. They are used also in all types of joint work, and for laminated beams, arches, and trusses. Some casein glues which do not stain wood are now available.

Blood Albumen Glues

These glues are prepared from fresh blood obtained from slaughtered animals or from dried soluble blood albumen (processed blood). The adhesive is prepared by adding water, ammonium hydroxide, hydrated lime, and a bactericide to the blood or blood albumen. Blood albumen is essentially a hot-press glue, although certain specially processed mixes may be cold-pressed. The latter do not produce such satisfactory bonds as do the hot-press blood albumen glues. The hot-press types require platen temperatures between 212° and 300°F. to produce a good bond. The bonds produced by these adhesives are highly water-resistant but are liable to fungus attack and deteriorate with the passage of time. Blood albumen glues are sometimes combined with phenolic resin glues.

Synthetic Resin Glues

These adhesives are of fairly recent origin. They have, in a number of cases, replaced some of the older types of glue such as animal, vegetable, and casein glues. The latter glues were restricted in use because of their inability to withstand conditions of moisture and bacterial attack. The synthetic resin glues are highly water-resistant, in some cases waterproof, and are not subject to attack by microorganisms. A glue is said to be water-resistant when it is capable of resisting conditions of high humidities and occasional exposure to water for short periods. A waterproof glue is one which is not affected by exposure to the weather, or by intermittent or prolonged contact with water. The synthetic resin glues require greater care in handling than do the previously named adhesives. Some of the precautionary measures to be taken are as follows:

(a) Glue storage: Adhesives should be stored in a cool, dry location. Synthetic resin glues polymerize through chemical reaction which is accelerated by heat and moisture. Therefore, poor storage conditions may cause deterioration of the resin, resulting in poor joints or total spoilage of the stock.

(b) Careful weighing of ingredients: Many synthetic resin glues require the addition of small quantities of ingredients. A slight error in weighing these ingredients will materially affect the properties of the adhesive.

(c) Cleanliness: These adhesives depend for effectiveness upon a carefully balanced chemical reaction which may be adversely affected by the presence of small quantities of alkali or acid in dirty containers.

(d) Wood moisture content: Some of these adhesives, particularly the "cold-setting" urea-formaldehyde resin glues, produce satisfactory joints only over narrow ranges of wood moisture content (30).

(e) Temperature control: Synthetic resin glues of the cold-setting type will not cure satisfactorily at temperatures lower than 72°F.; at higher temperatures, their rate of cure is greatly accelerated. Temperature changes will affect the "pot-life", assembly period, and curing period of the resin glue.

(f) Glue-spreads: Spreading of the glue should be carried out by means of mechanical-type glue spreaders equipped with reliable means of controlling the amount of glue spread on the wood. Too heavy a glue spread will result in a waste of glue and possibly in a thick glue line which may subsequently disintegrate (craze). Too light a spread may result in starved joints and blisters.

(g) Pressure: Insufficient pressure may produce thick glue lines which may result in crazing or open joints. Excessive pressures will result in starved joints and crushing of the wood, particularly in hot-press bonding methods.

A brief description of the various types of synthetic resin glues used in the woodworking and plywood industries follows.

Urea-formaldehyde Resin Glues

The manufacture of these glues is based on a reaction between carbon dioxide and ammonia. The urea thus formed is combined with formaldehyde and a suitable catalyst or hardener to form what is known as a urea-formaldehyde resin glue. These adhesives are thermosetting and may be subdivided into two main groups: (a) The cold-setting glues, which cure at 72°F. (b) The hot-setting glues which require temperatures between 200° to 260°F. to polymerize the resin.

The cold-setting (or room-temperature-setting) adhesives have a "pot-life" of from 3 to 6 hours, depending upon the catalyst and the temperature of the glue room. At 72°F., these adhesives cure within 4 to 6 hours, and at higher temperatures their rate of cure is considerably accelerated. Certain materials, for example grain flour, may be combined with these resin adhesives to provide body or to reduce costs, and are commonly called extenders (the flour used should be of the low ash and protein content type, for example, soft wheat flour). The glue may be extended with as much as 80 per cent flour and still retain a considerable portion of its unextended adhesive strength, when used in dry locations. However, when good resistance to water is required, these adhesives should not be extended beyond 40 per cent with flour. Generally, when extenders are used, it is necessary to increase the quantity of water used in the unextended mix by an additional amount equal in weight to that of the flour added. The spread used for these glues is from 35 to 50 pounds of glue per 1,000 square feet of surface, the lighter spreads being used for the denser woods and the heavier for the more porous.

The hot-setting urea-formaldehyde resin glues are used chiefly in the plywood industry. They are not readily affected by minor temperature changes and, therefore, have a long working life. Pressing time varies with platen temperatures, veneer thicknesses, and number of plies. Normally, glue spreads vary between 25 and 40 pounds of glue per 1,000 square feet of surface. Hot-setting urea-formaldehyde resin glues may be generously extended, even up to 200 per cent, with wheat or rye flour. The amount of flour extension depends upon the type of plywood required and its ultimate use. Highly extended mixes may be used for such applications as stock panels, furniture, drawer-bottoms, mirror-backs, and box-shooks.

Unextended urea-formaldehyde resin glues are highly water-resistant, being greatly superior in this respect to the casein glues; they are, however, not generally recommended for outdoor exposure, or where extreme moisture conditions may be encountered.

Melamine Resin Glues

Melamine is prepared from cyanamide (a product derived from calcium carbide and nitrogen) combined under carefully controlled conditions with formaldehyde to form an adhesive similar to hot-setting urea-formaldehyde resin, but possessing greater durability, for which reason melamine resins are sometimes combined with urea-formaldehyde resin adhesives. Melamine adhesives will bond wood over a wide range of moisture content, possess long working life and assembly time, and are non-staining: they cure at plate temperatures between 220°F. and 260°F. Their durability appears to be similar to that of the phenolic type resin glues. Melamine adhesives may be extended with grain flour, but little information as to the degree of extension possible and its effect upon the physical properties of the glue is yet available.

Since melamine glues are relatively new, their use to date has not been extensive. It is probable that the cost of producing these adhesives will be lowered, thus enabling plywood manufacturers to take advantage of their many good features.

Phenol-formaldehyde, Resorcinol-formaldehyde, and Phenol-resorcinol Resin Glues

Phenol or cresol is chemically combined with

formaldehyde to form phenol-formaldehyde resin glues. These adhesives are generally of the high-temperature-setting types requiring curing temperatures between 280° and 320°F. to polymerize. They are marketed in several forms—a dry powder (requiring addition of water, or alcohol and water), a liquid, and a prepared film glue (Tego); this latter type is used chiefly in the production of thin plywood. Phenolic resin glues are used in the production of high-grade, weatherproof, exterior-type or marine plywood. Certain types of phenolic resins contain small quantities of resorcinol or active hardening agents which serve to lower their curing temperature. These are designated as fast-curing or intermediate-temperature-setting phenolic resin glues. They will cure at temperatures between 160° and 280°F. Phenolic resin glues cannot be extended with flour to the same extent as can the urea resins, but certain fillers, such as walnut-shell flour or blood albumen, which serve to reduce the excessive flow of the resin, may be used. These do not materially reduce costs, as the quantities that can be used successfully without seriously impairing the strength and water-resistance of the glue bond are not significant.

Phenolic-type resin glues produce most durable and waterproof bonds. They are unaffected by fresh or salt water, and are very resistant to boiling water, alcohols, oils, gasoline and other solvents, wood preservatives, and fire-retardant chemicals. They are resistant to most acids, but may be affected by strong alkalis or strong oxidising acids. Because of their durability and waterproof qualities, they are used in many applications such as plywood for boats, aircraft, prefabricated houses, truck bodies, exterior doors, and, generally, where resistance to weather is an important factor.

Apart from the above-mentioned phenolic resin glues, there are resorcinol-resin glues which are often combined with phenolic resin to form phenol-resorcinol (resorcinol-phenol resin) glues. These adhesives are considerably more costly than the hot-setting types, but possess the advantage of setting at room temperature (72°F). They are used in a similar manner to the urea-formaldehyde room-temperature-setting resin glues. They do not generally require the same careful control of such factors as moisture content of the wood, assembly period, and clamping pressure as do the urea resins. They are used chiefly as assembly glues, but may also be used for all applications where waterproof and completely durable bonds are required.

Polyvinyl Resin Emulsion Glues

These adhesives are of recent development, and little information is yet available as to their durability and other characteristics. They are marketed as aqueous suspensions of polyvinyl resin (polyvinyl butyral, acetate, and chloride) or in combinations of these resins with plasticizers, fillers, and pigments added. These adhesives are marketed in ready-to-use form, are quick-setting like animal glues, and appear to be more water-resistant than the latter. Like casein glue, they may be used at temperatures below 70°F. although their rate of cure is slower. They are thermo-plastic in character and soften at temperatures above 160°F. They have, however, the disadvantage that joints show a tendency to creep when under continuous stress (31).

Bonding Metal to Wood

The bonding of two such dissimilar materials as metal and wood presents many problems. Metal, under the influence of heat and cold, expands and contracts, while wood is little affected by temperature changes. Wood, on the other hand, is markedly affected by moisture, swelling as the moisture rises and shrinking as it falls, while metal is entirely unaffected. The porous structure of wood enables glue to penetrate and form an anchor, while metal is entirely impervious. In view of these facts, a glue which will give a satisfactory wood-metal bond must necessarily have the following as its main characteristics: it must be flexible, to allow for the dimensional variations involved; its adhesive strength must depend on a combination of mechanical and specific (surface) adhesion; it must be waterproof or at least highly water-resistant.

The effectiveness of wood-to-metal bonds depends greatly upon the preparation of the metal surface before the application of the adhesive; it should be cleaned thoroughly to remove all traces of grease, corrosion, and scale.

Following are listed some of the adhesives and techniques employed in the gluing of metal to wood: (a) flexible glue is applied to the metal surface and is allowed to dry; resin glue is applied to the wood and the coated metal surface, which are then pressed together in a cold-press; (b) latex-casein glue is applied to both surfaces, which are then assembled

and cold-pressed; (c) thermo-plastic resin glue is applied to both surfaces and allowed to dry; the assembly is then bonded under heat and pressure and allowed to cool before removal from the press; (d) thermo-setting glues are used to some extent; they are applied to both surfaces and allowed to dry, and are then hot-pressed in the usual manner (32).

Effect of Wood Moisture Content on Gluing

Because of the many different types of glues and the diversified uses being made of laminated wood for aircraft, boats, dwellings, and furniture, it is important to appreciate that the moisture content of the wood to be glued plays an important part in the stability and effectiveness of the joint, regardless of the type of adhesive used.

Certain types of adhesives, such as animal, vegetable, and casein glues, depend for hardening upon the removal of water from the joint area. Hence, high wood moisture content retards the setting of the glue, introduces serious drying problems, and may, owing to excessive flow, or to severe stresses set up during the drying process, result in poor joints. Low moisture content of the wood results in fast

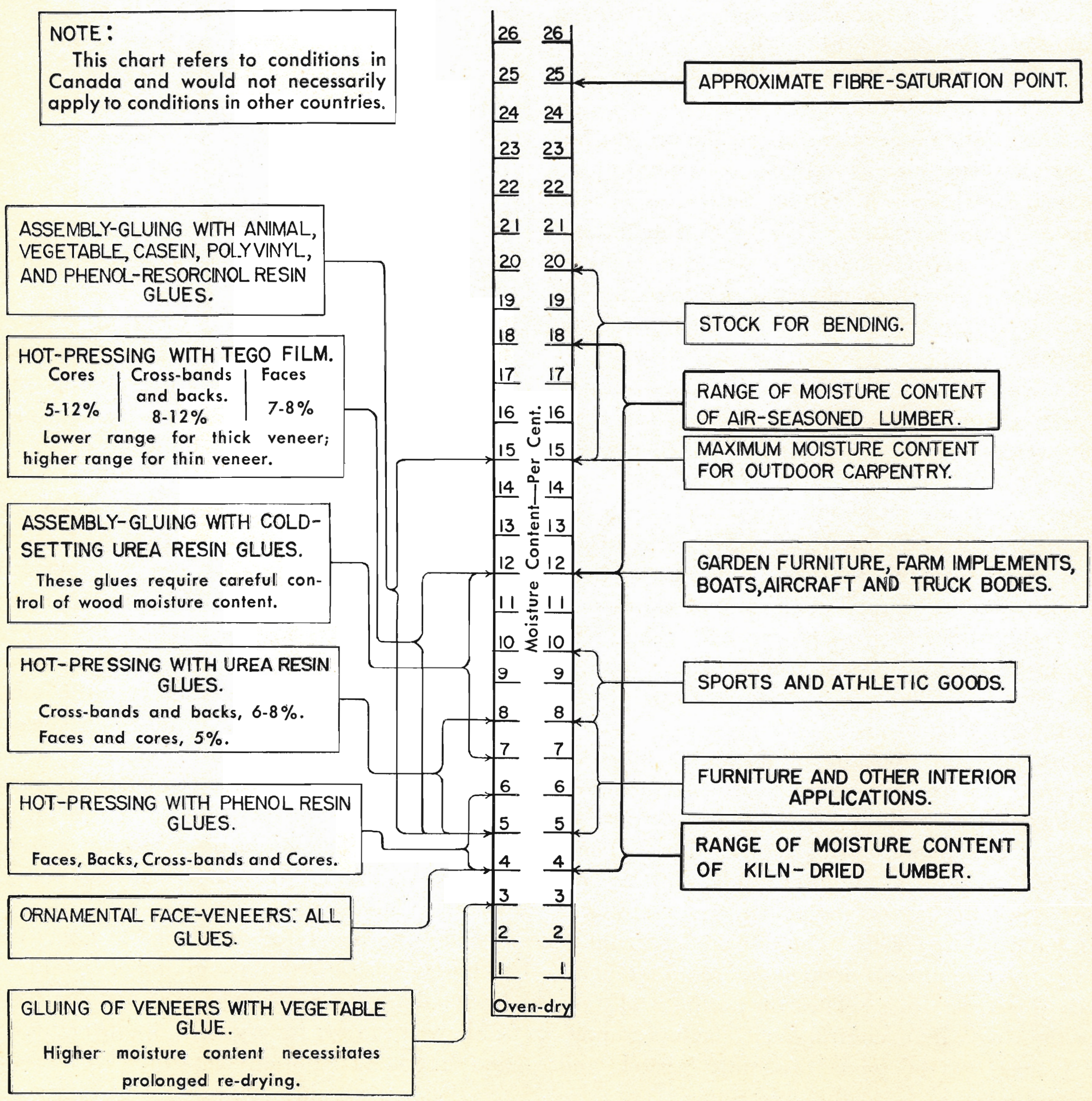


FIGURE 36.—Wood Moisture Contents Suitable for Gluing and Other Applications.

curing, little penetration of the adhesive proper into the wood, and the development of stresses in the wood caused by the addition of moisture from the glue line.

In the case of the synthetic resin glues, careful control over the moisture content of the wood is important. These glues depend for curing upon a chemical reaction which is independent of the diffusion of water from the glue line. The majority of these adhesives contain but a small percentage of water and, therefore, sufficient moisture must be present in the wood to serve as a vehicle to facilitate glue penetration. Lack of moisture results in little penetration of the glue into the wood and, consequently, the joints are weak. Excessive moisture in the wood, besides causing too much penetration of the adhesive, may result in warping of the wood upon drying to its equilibrium moisture content. Certain types of synthetic resin glues, such as the room-temperature-setting urea-formaldehyde resins, are very selective and produce good joints only within a narrow range of wood moisture contents (30). Hot-pressing methods used for certain types of resin glues introduce other problems, such as the formation of steam blisters and excessive flow, should the moisture content of the wood be too high. To summarize, in arriving at the proper wood moisture content, the following factors should be taken into consideration: (a) the type of glue, (b) the service conditions which the finished articles will be required to withstand (33).

Figure 36 indicates the appropriate wood moisture content for gluing and other general applications.

Gluing Pressure

Pressure in gluing serves: (a) to spread out the glue into a continuous thin film between the joint faces and (b) to hold the wood surfaces in position until the glue has developed sufficient strength to withstand stresses that may occur in the joint as a result of drying, or in subsequent manufacturing processes.

Therefore, in deciding the pressure to be applied to a glued assembly, consideration should be given to: (a) the consistency of the glue at the moment the pressure is applied, a thick glue requiring a heavy pressure and a thin glue a light pressure, (b) the type of wood—high-density woods require higher pressures than do those of low density, (c) condition of surface—well-matched, smooth surfaces require lighter pressures than rough-sawn wood surfaces, and (d) type of construction—heavy laminated constructions require high pressures and longer pressing periods than do lighter constructions.

Because of the many factors involved in assembly gluing methods, pressures may range from 75 to 150 pounds per square inch for the low-density woods and from 100 to 250 pounds per square inch for the high-density species. In the manufacture of plywood, pressures used generally cover a narrower range than in assembly gluing operations. When hot-pressing the low-density woods, pressures between 150 and 175 pounds per square inch are maintained, whereas for the dense woods pressures are generally between 200 and 250 pounds per square inch.

Glue Spreads

Glue spreads are generally expressed in terms of pounds of liquid glue mix per 1,000 square feet of single glue line. If the glue is to be applied to both the surfaces to be joined, one-half the recommended spread is applied to each surface.

Among the factors affecting glue spread are: type of glue, wood species and density, condition of surface, type of construction, method of glue application, etc. Ordinary cold-setting glues, such as animal, protein, and casein glues require spreads of from 50 to 90 pounds per 1,000 square feet of single glue line, whereas the synthetic resin glues require only from 25 to 50 lbs. under similar conditions. Glue spreads should in all cases be governed by the manufacturer's recommendations in conjunction with practical shop experience. Various methods of applying glue are used commercially, for example, hand brushing, dipping, spraying, and mechanical roll spreading. The latter is by far the most efficient for dealing with large, flat surfaces.

TESTING OF GLUES

THE test methods commonly used at the Forest Products Laboratory to determine the quality of a glue and of glued joints are:

Physical Tests	***Mechanical Tests***
Viscosity	Block-shear
Jelly Strength	Tension-shear
Acidity (pH value)	Plywood-shear
	Tension normal to glue line

Viscosity (Animal Glue)

This test is carried out on a 12.5 per cent solution of animal glue at 60°C by means of a standard pipette viscosimeter, the temperature of which is maintained by a water-jacket. The pipette is so calibrated as to permit the time (in seconds) taken by 100 cc. of the glue solution to pass through the capillary tube of the instrument to be readily converted into millipoise units, a standard measure of viscosity (34).

Jelly Strength (Animal Glue)

Jelly strength is determined on a 12.5 per cent solution of glue cooled in a water-bath for 16-18 hours at a temperature of 10°C. The determination is carried out on a Bloom Gelometer, now adopted as the standard instrument, which measures the weight in grams required to give a 4 mm. depression of a plunger of known area into the surface of the standard glue jelly. The size of the plunger and the shape and volume of the glue container used for this test are part of the standard requirements (34).

Acidity (pH value)

Some synthetic resin glues, because of the nature of the hardening agent, produce, while setting, an acid exudation which might possibly weaken the wood fibres in the vicinity of the glue joint or affect the constitution of the glue film itself. The following method is used to determine the acidity of resin glues.

The adhesive is mixed according to the manufacturer's instructions. It is spread out in a thin even coat on a sheet of clean glass. The film is allowed to dry for 12 to 15 hours at room temperature, after which it is peeled off and ground in a clean mortar to a fineness of 30 to 40 mesh. After grinding, 2 grams are placed in a glass container with 10 cc. of distilled water. The pH of the suspension is determined after 15 minutes from the time of addition of the water, by a suitable electric pH instrument having glass electrodes. The pH of the suspension is further measured at 24, 48, 72, and 96 hours, or until the pH determinations become constant. The final pH value of the glue should be not less than 2.5.

Block-shear Test

This is a general test normally used to determine the dry adhesive strength of assembly glues. The

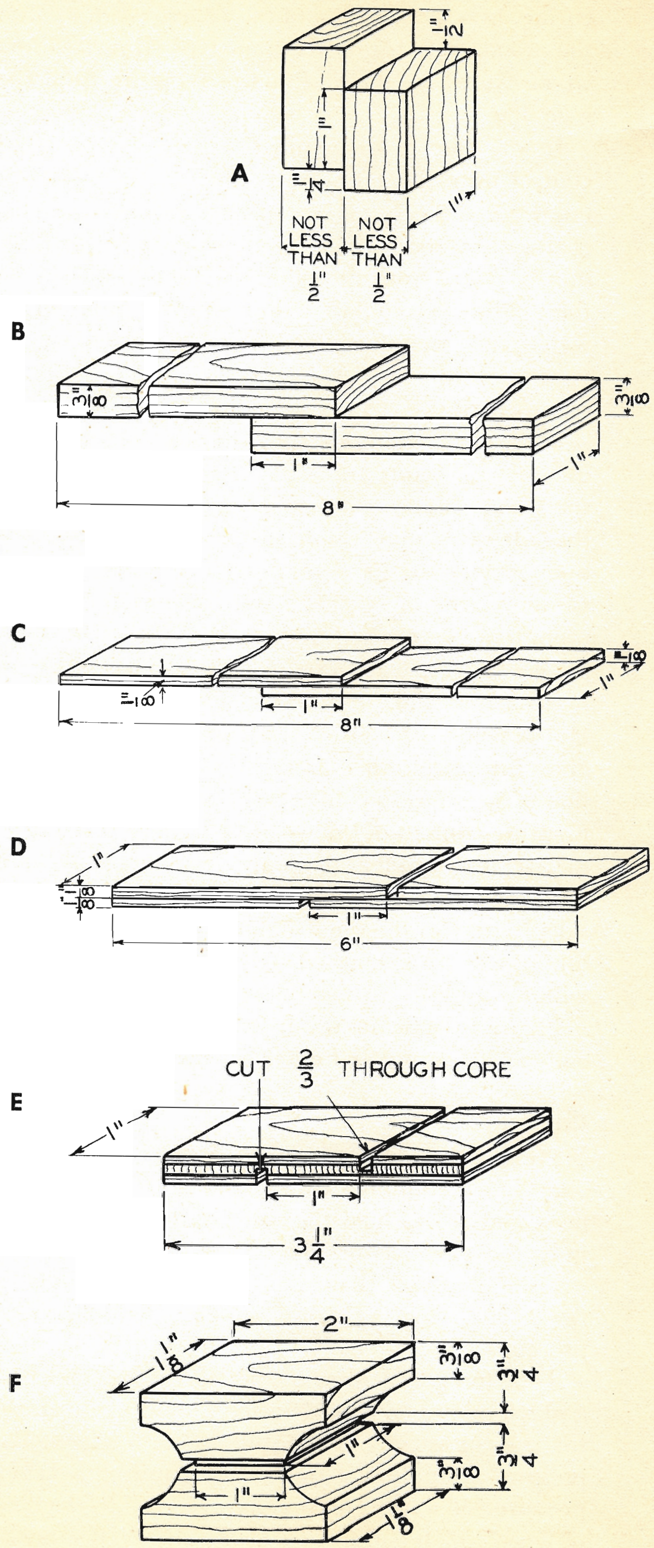


Figure 37.—Specimens for Testing Wood Adhesives.

standard procedure is to apply the adhesive to two strips of straight-grained sugar maple 2½ inches wide by three-quarters of an inch thick, and 13 inches long. These blocks are placed in a jig, and a pressure of 150 pounds per square inch is exerted uniformly over the full area of the test block. The blocks are generally allowed to remain under pressure for a period of 16 to 24 hours. After curing 4 to 7 days, the blocks are cut into standard 1″×1″ shear block specimens, as shown in Figure 37A. Some specifications require a glued area of 3 square inches.

Tension-shear Test

There are three types of tension-shear specimens in use at the present time for the evaluation of the mechanical strength properties of glues and glued joints:

(a) 1-inch lap-joint on three-eighths-inch sugar maple strips 1 inch wide (see Figure 37B). This test is required by certain specifications for determining the wet and dry strength properties of casein and room-temperature-setting resin glues.

(b) 1-inch lap-joint on one-eighth-inch yellow birch veneer (see Figure 37C). This specimen is tested in a similar manner to the three-eighths-inch maple test specimen.

(c) 2-ply one-eighth-inch yellow birch specimen (see Fig. 37D). This is a modification of the specimen shown in Fig. 37C. It is less subject to bending action than is the lap-joint specimen and gives a truer shearing action under test.

Plywood-shear Test

Although this test has been used principally in testing plywood glues, it is now being used extensively for all types of adhesive. This method of test is described fully elsewhere in this chapter under Plywood Testing, page 258 (see Figure 37E).

Tension Normal to Glue Line Test

This test was originally developed to supersede the knife test for determining the quality of the bond between the various veneers in a plywood panel; the design of the test specimen is shown in Fig. 37F. Tongue and groove and other irregular glued joints, which cannot be tested satisfactorily by the usual shear block method, can be conveniently tested by this procedure (35).

DIELECTRIC HEATING

by R. W. PETERSON

DIELECTRIC heating is a method of utilizing electrical energy in the form of radio-frequency power for heating non-conducting materials such as wood. There are various methods for heating wood but, regardless of the method employed, the same number of heat units are required for a given rise in temperature. While dielectric heating is not the cheapest method of supplying the necessary energy, it does offer definite advantages in many cases: for example, it is the only method whereby the heat can be generated uniformly throughout the wood regardless of thickness, also, in certain wood-bonding applications, the heat can be generated principally in the glue lines. These two features make the use of dielectric heating advantageous for many wood-bonding operations.

Principles of Dielectric Heating

When an insulating or dielectric material such as wood is placed in a rapidly alternating electric field, the molecules are vigorously agitated, thereby creating "molecular friction" which causes heat to be generated uniformly throughout the material. The more rapidly the field alternates, or, in other words, the higher the frequency of the electric field, the lower the voltage required. In the case of wood, the amount of heat generated in this manner is also dependent upon two properties of the wood being heated, known as the dielectric constant and the power factor: the higher the value of these two properties, the greater the amount of electrical energy converted into heat for any given voltage and frequency. The values of these properties of wood vary considerably, increasing both with the density of the wood used and its moisture content (see p. 278). The amount of radio-frequency power applied to a dielectric material by this method can be calculated by the following formula:

$$P = \frac{1.415 \times 10^{-6} \times f \times E^2 \times K \times \mathrm{Cos.}\theta}{d^2}$$

where P = power in watts per cu. in. of material

f = frequency of the applied voltage in millions of cycles per second.

E = electrode voltage

K = dielectric constant of the material

Cos.θ = power factor of the material

d = thickness of material between electrodes in inches.

The frequencies used for dielectric heating range from 1 to 30 million cycles per second and are known as radio frequencies. Commercial electric power at frequencies of 25 and 60 cycles per second is converted to these frequencies by means of dielectric heating units.

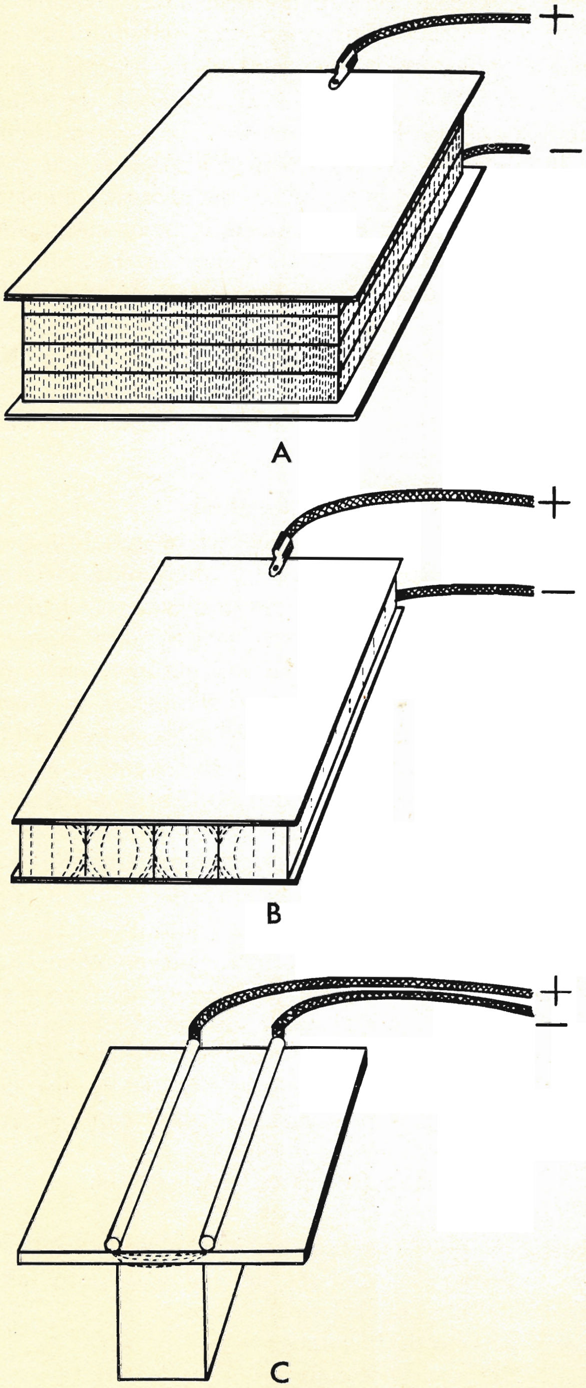


FIGURE 38.—Methods in Dielectric Heating. A.—transverse; B.—parallel; C.—stray-field.

The method of applying the radio-frequency power to a piece of material which it is desired to heat is to place the material between two metal sheets or plates known as electrodes. These electrodes are in turn connected to the output terminals of the dielectric heating unit. Although the principle of heat generation is the same in all cases, wood bonding operations may be considered under three general classifications, according to the manner in which the electrodes are placed relative to the glue line. These three general methods of heating are known as transverse heating, parallel heating, and stray-field heating.

Fig. 38A illustrates the transverse heating method. The electrodes are so placed, relative to the glue lines, that the electric field, which is represented by the dotted lines, is perpendicular (or transverse) to the glue lines; by this arrangement the electric field is uniformly distributed throughout the load, resulting in uniform heating of the wood and glue lines. The second method, known as parallel heating, is illustrated in Fig. 38B. In this case the electrodes are placed on the glued assembly so that the electric field is parallel to the plane of the glue lines. The wet glue lines provide a much easier path for the electric field to follow than does the relatively dry wood, with the result that the field concentrates in the glue lines, as shown by the dotted lines; this concentration of power results in rapid curing of the glue. This procedure is also known as glue-line heating, or selective heating. Fig. 38C illustrates the third method, known as stray-field heating. The electrodes are made of rods, tubes, or strips of flat metal which are placed above and on either side of the glue line to be cured. The resulting electric field is curved, and travels through the wood and glue line as again shown by the dotted lines. This method is employed where it is not possible or practical to place the wood and glue lines directly between the electrodes.

Applications of Dielectric Heating

Bonding of Laminated Wood Products

In the manufacture of thick laminated products, dielectric heating offers an expeditious method of applying heat to accelerate the rate of cure of the glue. Other methods are comparatively slow, as they are dependent on the transfer of heat from the surfaces of the assembly to the glue lines by conduction

through the wood. The transverse heating method is normally employed for this type of work, as by it the temperature of the total assembly is quickly raised to that required to cure the glue.

Laminated golf-club heads, hockey sticks, bowling pins, and structural members are examples of wood products being turned out by this method. The bonding time will depend upon the volume of wood to be heated, the curing temperature of the glue used, and the amount of radio-frequency power applied. Knowing the curing temperature of the glue, the number of heat units required to raise the temperature of the wood and glue to the required level for any transverse heating application can be calculated by the following formula:

$$H = W \times S\ (T_2 - T_1)$$

where H = heat units in B.T.U's
W = weight of wood in lbs.
S = specific heat of wood
T_1 = initial temperature in °F.
T_2 = final temperature in °F.

Fifteen per cent should be added to the figure obtained by this formula, to allow for stray losses. Using the relationship 1kw. = 57 B.T.U's per minute, the heating time for any given power, or the power required to cure the glue in any specified time, can be calculated.

Bonding Plywood

Dielectric heating offers few if any advantages over conventional multi-opening hot platen presses for bonding flat plywood of less than one inch in thickness. However, for the bonding of very thick plywood, where heat flow problems assume considerable importance, the application is more promising.

For the bonding of curved plywood, the situation is quite different. Moulds of the desired shape can be readily and cheaply constructed of wood and covered with sheet copper to serve as electrodes. In this way the shape of the product can be quickly and cheaply altered, as compared to the cost if heavy metal platens were used. For simple plywood shapes, solid male and female forms may be employed. For more complicated shapes, it might be necessary to make one form in segments which could be brought into position separately during the bending process. The pressure required is of the order of 100 to 150 p.s.i. and the method of applying the pressure will depend on the shape and design of the forms. In some cases, air-inflated fire hose provides a convenient method of applying the necessary pressure. The moisture content of the veneers to be bonded should be less than 12 per cent, to avoid difficulties due to blistering.

One of the chief problems in bonding curved plywood by dielectric heating is that of designing moulding equipment which can be unloaded and reloaded quickly enough to take advantage of the short curing cycles possible. An experimental press for bonding U-shaped sections was designed at the Ottawa Laboratory, and a working model was constructed. This press utilizes air-operated cylinders

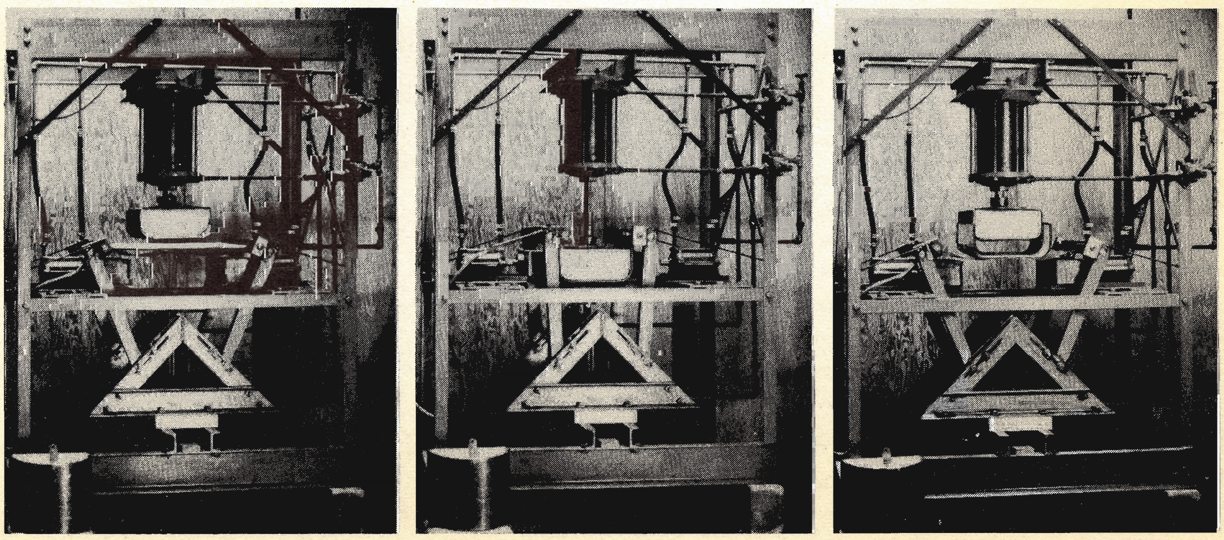


PLATE 95.—Press for Producing Curved Shapes by Dielectric Heating.

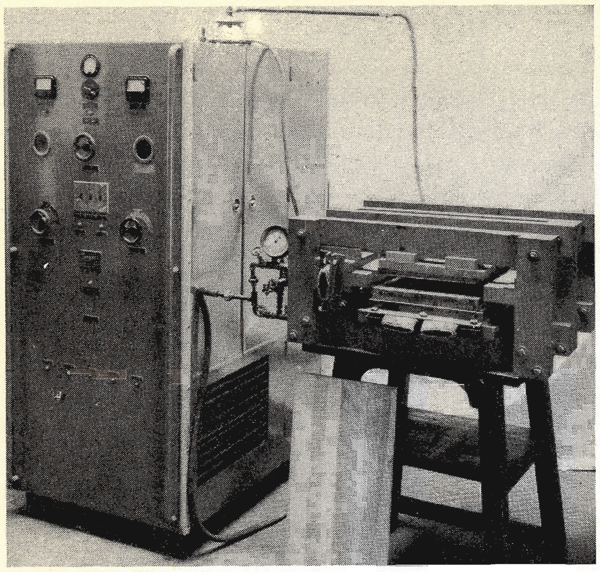


PLATE 96.—Edge-gluing by Dielectric Heating.

to supply the necessary action and pressures. A sheet copper pressure band serves to bend the veneers around a male form, and also as the outer electrode for the heating process. Press cycles obtained with this press are of the order of 1 to 2 minutes (36).

The time required to cure the glue in an application of this kind depends upon the type of glue used, the volume of wood to be heated, and the amount of radio-frequency power utilized. Room-temperature-setting resins are most suitable for this work, but any of the synthetic resins may be used. Calculations of the curing time and power requirements can be made by using the formula given on p. 273. Among the advantages of the process are: very short curing cycles requiring few, inexpensive forms and little floor space; the outer veneers are not dried out, as is the case with heated platens; there is consequently less tendency for warping and springback to occur.

An extensive application is for patching operations in the manufacture of flat plywood. Very small dielectric heating units are employed, with the electrodes incorporated in the form of a hand gun. Small patches may be inserted and the glue cured in a matter of seconds by this method. These small units are considerably less expensive than standard dielectric heating units, and with special attachments may also be used for minor assembly gluing.

Edge-gluing of Lumber and Veneers

The parallel heating electrode arrangement is employed for the edge-gluing of lumber and veneers. It is in this application that advantage can be taken of the so called "selective heating" or "glue-line heating" to obtain high efficiency. The curing cycles are very short, and the glue is heated and cured before appreciable heat is generated in the wood.

As is the case with all edge-gluing techniques, the preparation of the stock is of prime importance. The edges to be bonded must be flat and square, to ensure good wood contact the full length of the joint. The amount of warp which can be tolerated is dependent upon the ability of the machines in the pre-gluing operations to hold the stock flat while cutting. It has always been considered good practice to prepare the stock for edge-gluing immediately prior to bonding. This ensures clean, true surfaces, with a minimum danger of unevenness occurring in the surfaces owing to changes in moisture content after jointing. Equally satisfactory joints can be obtained with ripped or jointed edges, provided sufficient edge pressure is used. The optimum pressure for hardwoods is approximately 250 p.s.i. Below this pressure, jointed surfaces tend to give stronger joints than ripsawn surfaces. Care should be taken to avoid knots at the joints, as they tend to weaken them. It is particularly important to eliminate knots when resinous woods are being bonded, as they tend to cause a breakdown of the electric field and arcing at that point.

The room-temperature-setting urea resins have been found most suitable for edge-gluing by dielectric heating. The greatly accelerated rate of cure which accompanies an increase in temperature of these glues accounts for the very short curing cycles which make the process feasible. All the room-temperature-setting urea resins are not equally satisfactory, as some are much more sensitive to treatment by dielectric heating than are others. For this reason, when choosing a suitable glue for this work, the manufacturer should always be consulted. If a greater degree of water resistance than can be obtained with a urea resin is required, the room-temperature-setting resorcinol and melamine resins can be used. They require more power to cure than do the ureas, but can be used quite successfully. The phenol formaldehyde resins are not recommended for edge-gluing, as they are very susceptible to arcing and require very high temperatures to cure.

Conventional glue spreaders of the roller type, having corrugated rubber rolls, are employed to obtain a controlled uniform spread. This is important if uniform heating and strong joints are to be obtained. Too heavy a spread results in excessive

squeeze-out, which is wasteful of glue and may cause trouble in removing the bonded assemblies from the press, as it tends to adhere to the electrodes. The glue manufacturer's recommendations should be followed with regard to the weight of spread to use.

Small presses, using air-inflated fire hose to apply necessary pressure, may be cheaply and simply constructed (Plate 96). Edge-gluing presses of two types are available, the continuous process type and the batch press type, the latter being much the more widely used. The batch type presses are made in a variety of sizes, according to the maximum size panel which they will bond. Presses for panel sizes up to 50″ by 100″ are readily available. The presses normally employ solid electrodes and, when such is the case, complete curing of the glue lines is obtained. An alternative arrangement is a grid electrode system which produces only a partial cure of the glue lines. When such electrodes are used, the panels must be stacked to allow the remainder of the glue to cure before further machining. The commercial presses are almost completely automatic, and their rate of production is dependent primarily on the time required to lay up the stock. The units are capable of giving bonding cycles of 15 to 30 seconds; however, the average lay-up time is normally longer than this. Assuming a lay-up time of 1 minute for a 40″ by 80″ press with 1″ stock, the rate of production would be approximately 1300 ft.b.m./hr. Actual production may be higher or lower, depending upon operating conditions.

Calculations of the power required for edge-gluing are complicated by a large number of variables such as wood density, wood moisture content, thickness of stock, average width of boards, duration of the curing cycle and type of glue used. The curves in Fig. 39 give the relationship between total inches of glue line, curing time, and power for 1″ dense wood with an average width of 3″ and having a moisture content of 6 per cent. A similar set of curves for light wood under the same conditions appear in Fig. 40. For higher wood moisture contents more power is required: at 20 per cent moisture content, approximately 40 per cent more power is required than at 6 per cent. On the basis that the press cycle is controlled by the lay-up time rather than the time necessary to cure the glue, the most efficient operation is obtained by using the smallest dielectric unit and the longest glue-curing time consistent with the press cycle or minimum lay-up time (37).

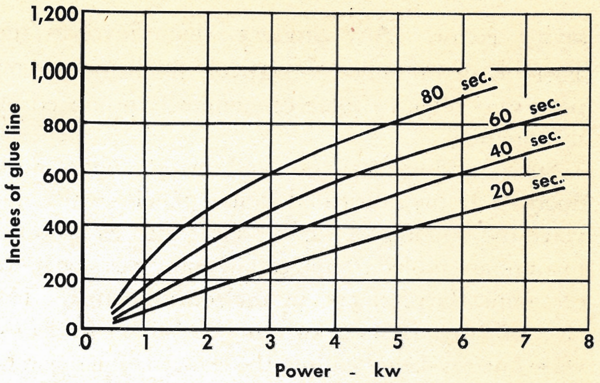


FIGURE 39.—Power Curves for Edge-gluing Yellow Birch at 6% Moisture Content (average air-dry density, 43 lbs. per cubic foot).

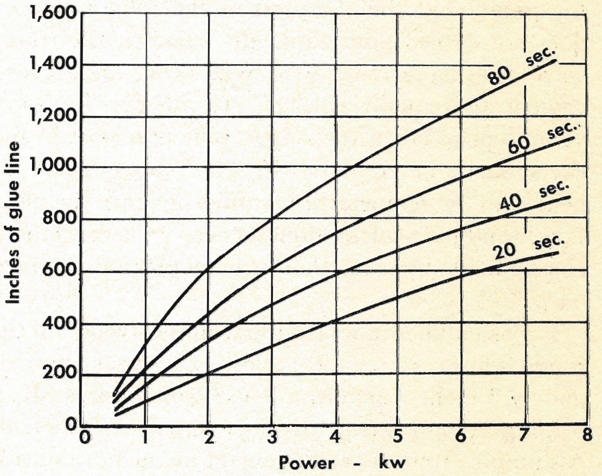


FIGURE 40.—Power Curves for Edge-gluing Aspen Poplar at 6% Moisture Content (average air-dry density, 28 lbs. per cubic foot).

Some advantages of the process are high production, ease of operation, minimum floor space required, the equilibrium moisture content of the lumber is not disturbed, and the panels are ready for further machining on removal from the press, with little danger of sunken joints. The process is also being used for edge-gluing core veneers of 1/8″ or more in thickness in special tapeless splicing machines.

Assembly Gluing

Dielectric heating is extensively used for assembly-gluing operations of all kinds. In the manufacture of such products as radio and television cabinets, electrodes of copper or stainless steel are incorporated in jigs. By this procedure, the bonding time is shortened to 2 or 3 minutes, greatly reducing the number of jigs required. The elimination of glue blocks and holding nails or screws is also an important labour-

saving factor. Any product which involves the assembly of a number of relatively small component parts may often be more economically produced by this method.

Such products as desk and dresser ends, flush doors, and pre-fabricated house panels, which involve the bonding of a cover sheet such as plywood to a pre-assembled frame, can in many cases be more economically produced by dielectric heating. The electrode arrangement used may be either for transverse or stray-field heating, the choice being dependent upon which arrangement will be more efficient for the particular application in question. Generally speaking, if the volume of wood in the frame is not too great, and the thickness of the total assembly does not exceed approximately 3 inches, the transverse heating arrangement will prove more convenient and equally efficient. In this case the total volume of wood in the frame, plus that part of the cover sheet in contact with the frame, must be heated to the temperature required to cure the glue. Power and time calculations for such an arrangement can be made by using the formula previously given on p. 273.

For assemblies in which the volume of wood in the frame is large, or the total thickness exceeds approximately 3 inches, such as a house panel, a stray-field heating arrangement may prove more efficient. A suitable electrode arrangement for such an operation is shown in the sketch in Figure 41. The electrodes are in the form of bars or rods mounted on and insulated from the pressure assembly. The electrodes should be spring-loaded, to ensure good contact between the electrodes and the wood without causing severe strain in the mountings. If it is desired to bond a cover sheet to both sides of the frame, a second similar electrode arrangement may be placed on the opposite side and the complete assembly bonded in one operation.

General

Dielectric heating can be used to best advantage when treated as a mass production tool. The presses and jigs should be so constructed that they can be quickly loaded and unloaded to take advantage of the very short bonding cycles. In many cases it is advantageous to have two sets of forms or jigs, so that one set may be unloaded and reloaded while the other is being heated. In this way the dielectric heating unit may be kept in operation approximately 90 per cent of the time and its full production realized at lower cost.

Figure 42 gives many current applications as well as probable applications which have not been discussed. The disadvantages of dielectric heating for many applications lie not in the quality of the work produced but in the initial and operational cost of the equipment. A great deal of research remains to be done if full advantage of the process is to be realized by the wood-working industries.

Research

Since 1945, the Ottawa Laboratory has carried out considerable research in the field of dielectric heating, with a view to developing new applications of its use in the wood industries, as well as improved techniques for applications presently in use.

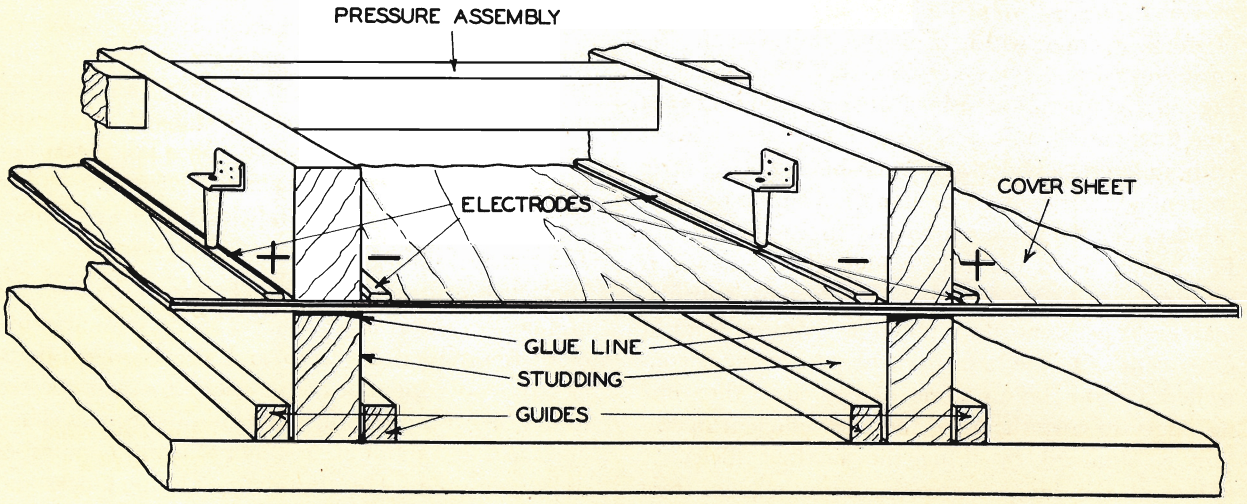


FIGURE 41.—Electrode Arrangement for Stray-field Heating.

			Industrial Applications	*Under Investigation*
BONDING	PLYWOOD	FLAT	Fir plywood (Large-scale production) Special thick plywood Patching	
		CURVED AND MOULDED	Waterfalls Drawer fronts Radio cabinets Piano rims Station Wagon bodies Musical instruments Chair seats and backs Cylindrical containers House trim 'Juke' boxes School desks and seats	Canoes Caskets Trunks
	LAMINATED PRODUCTS		Golf club heads Hockey Sticks Bottle containers Chair legs and arms Boat ribs and keels Structural members Arches Aircraft spars Bowling pins Paint brush handles	Skis Shoe last blanks Laminated railway ties
	EDGE-GLUING		Core-stock Dimension stock Lithograph blocks Box shooks Veneers Table tops	Shingles
	ASSEMBLY-GLUING		Furniture Pianos 'Juke' boxes Aircraft Radio cabinets Prefabricated house panels Paddles Flush doors	Pencils
HEATING	SEASONING		Dimension stock	Moisture content specimens Shoe last blanks Structural timbers Bowling pin blanks
	CURING		Compregwood	Impregwood
				Veneer logs Bending solid stock Sounding boards
SPECIAL				Sterilization Paper treatment Paper drying

FIGURE 42—Applications of Dielectric Heating in the Wood Industries

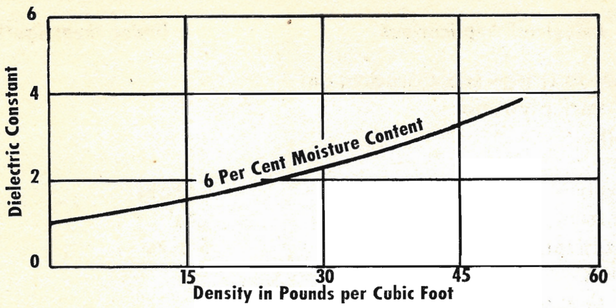


FIGURE 43.—Variation of Dielectric Constant with Density.

In addition to investigations of all wood-bonding processes mentioned previously, studies were made to investigate the possible use of dielectric heating for seasoning lumber. As heat could thus be generated within the wood, it appeared to offer a rapid method of drying wood from the inside out with a minimum of the usual seasoning defects. Results of the investigation indicated that, in most cases, it was technically possible to season lumber quickly by this method. However, a study of the economics involved indicated that the cost would be prohibitive for drying large quantities of lumber on a commercial scale. The process may, however, be of value in the seasoning of small dimension stock for special products.

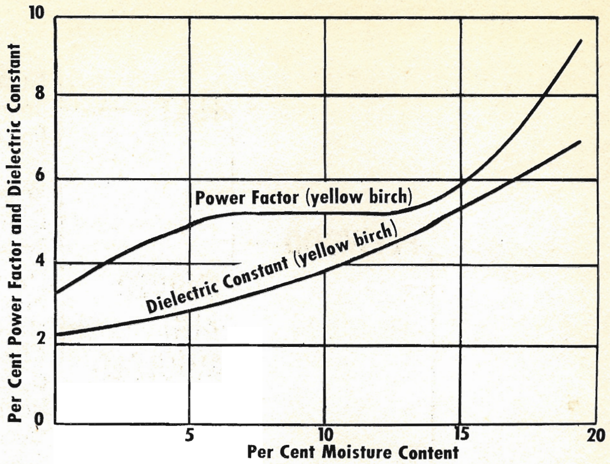


FIGURE 44.—Variation of Dielectric Properties with Moisture Content.

A great deal of research remains to be done in this field (38).

Basic data on the dielectric properties of wood were very limited and investigations were undertaken to determine the dielectric constant and power factor of wood according to wood density and moisture content. Typical curves are shown in Figures 43 & 44 (39).

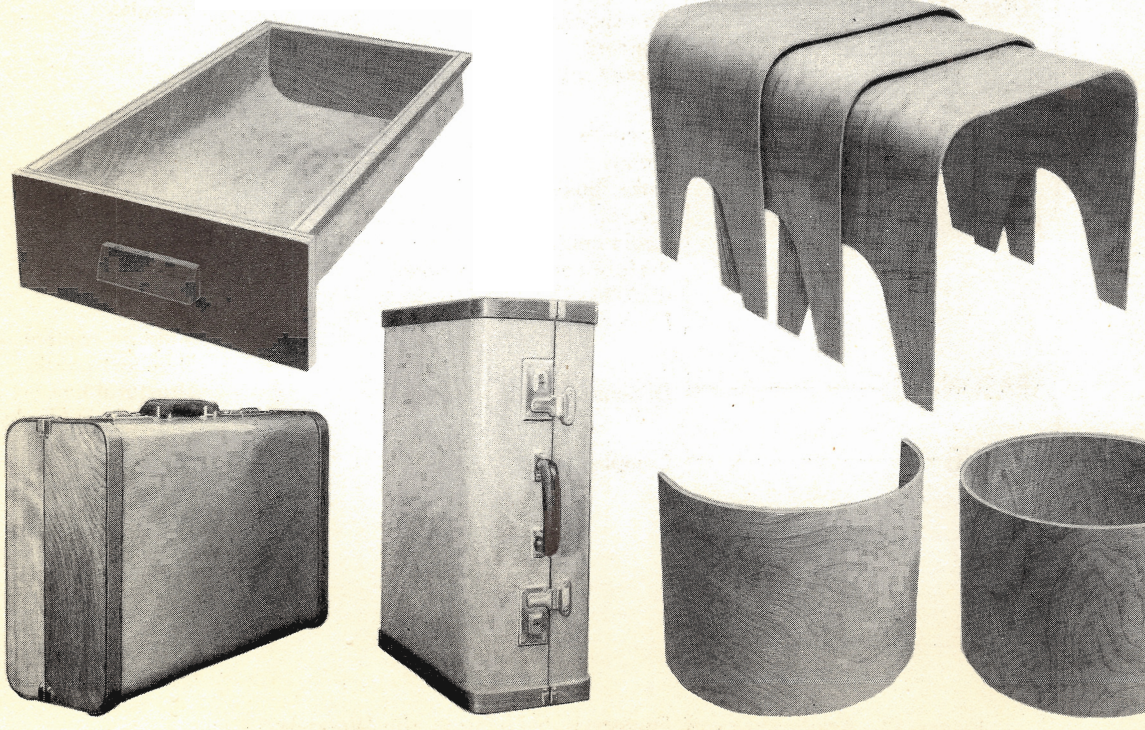


PLATE 97.—Various Applications of Curved Plywood.

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CHAPTER 11

GLUED, LAMINATED CONSTRUCTION

by D. E. KENNEDY

Definition

THE term *laminated construction* is used herein to describe those wooden structures or structural components built up of several layers of wood whose grain directions are all substantially parallel. It should not be confused with *plywood*, which refers generally to sheets of cross-banded veneers with the grain of each ply at right angles, or nearly so, to that of the adjacent ply or plies.

Laminated wooden members may be fastened together by nails, clamps, bolts, dowels, or glue. It is proposed here to deal only with *glued*, laminated construction, as this is one of the most modern methods, and is, in many respects, the most satisfactory.

History

Glued, laminated construction, so far as the North American Continent is concerned, is a fairly recent development. It began in a small way in the latter part of the thirties, and did not achieve sizeable proportions until the beginning of World War II. At that time, the acute shortage of steel for the construction of large military and civil buildings provided the needed stimulus to promote large-scale use of glued, laminated structural members.

While this may be considered a rather novel type of construction in North America, it has long been an accepted practice in Europe, where it was introduced prior to World War I. It has been extensively used in Germany, Sweden, and Switzerland, and, to a lesser extent, in other European countries. This type of construction, therefore, has long passed the experimental stage, and has stood up in practical use over a long period of time.

Uses

Some structural members or components for which laminated construction can be readily adapted are:

1. Beams and girders.
2. Posts and columns.
3. Arches.
4. Bowstring truss chords.
5. Dredge spuds.
6. Ships' keels, knees, etc.
7. Masts.

Disadvantages

No form of construction, be it steel, concrete, or timber, is without some disadvantage inherent in the particular material or in the construction technique. The chief disadvantages of glued, laminated construction, as compared with the use of large, sawn timbers, are as follows:

1. There is an appreciable wastage of lumber, the amount depending upon the size and shape of the structural member and the thickness of each lamination. In a nominal 2-inch board, for instance, approximately ⅜-inch will be lost in planing the two faces; if it is necessary to dress the edges, an additional half inch will be lost from the width of each board; and, if several laminations have to be

end-jointed, the loss will amount to about one foot of length per joint per inch of lamination thickness.

2. Glue of high quality must be purchased in fairly large quantities.

3. Buildings and equipment must be provided for the fabrication of the laminated product.

4. Labour and supervision costs are higher than for certain other forms of timber construction.

Advantages

1. The size of structural members is no longer limited by the size of accessible trees. Transportation limitations and considerations of economy are the chief factors which limit the size of laminated timbers.

2. Trees too small for the production of large timbers will yield material perfectly satisfactory for laminated construction, the supply of available material being thus significantly enlarged.

3. Species especially suitable for construction purposes, but which do not occur naturally in large sizes, are rendered available by laminated construction.

4. Low-grade lumber, i.e., lumber containing numerous knots, can be utilized in those sections of laminated timbers where compression or tension stresses will be low.

5. The lumber used can be seasoned to an optimum moisture content before assembly more easily and more quickly than is possible with large sawn timbers. Moreover, development of checks due to shrinking will be minimized, and higher shearing stresses can thereby be developed. Laminated timber is dry when erected, and its strength is greater and its deflection less than in the case of a sawn timber, which may be erected and loaded in the green or partially seasoned condition.

6. A camber can easily be built into a laminated beam, so that when it is subjected to loading it will appear not to have deflected at all.

7. Curved members, such as arch ribs, may be constructed simply by bending thin boards to the required curvature. This opens up a field of structural design in which large sawn timbers could have no place, as it is not possible to bend them.

8. It is sometimes possible to avoid the use of ring-connectored joints by making the chords of trusses one continuous laminated member.

9. In some types of structures, it is possible to taper the section of the laminated member in proportion to diminishing stresses. This may result in both a saving of material and in the production of a more graceful structure.

10. Other factors being equal, the variation in strength from one laminated timber to another will be less than in large, sawn timbers. The natural variability of the species is partially "averaged out" by putting together a number of different pieces to make up a single timber.

11. Subject to the limitations imposed by differential shrinkage and expansion with changing moisture content, it is possible to employ two or more species in the same structural member, thereby taking advantage of the economy of a low-strength species and the superior qualities of a high-strength wood.

Species of Wood

The softwood species which have proved satisfactory for general structural uses will, in most cases, be found equally suitable for glued, laminated construction. Softwoods are more commonly used for buildings and bridges because of their low cost, lightness, and strength, and these factors recommend them equally for use in laminated form. Certain special applications, however, such as glued, laminated ships' keels, may necessitate the use of hardwood species. A species favoured for this type of construction is white oak, a wood well adapted for use in both fresh and salt water.

Some species are more difficult to glue than others, and this may sometimes influence selection. However, with proper gluing procedure, a bond which will develop the full shear strength of a softwood species is usually obtained without difficulty.

Type of Glue

There are many types of adhesive on the market, and nearly all will develop an adequate bond with softwood lumber if properly used. However, the fabrication and use of glued, laminated members involves factors which combine to make one or two of these glues more suitable for a particular use than any of the others. The chief glues used for this purpose, with their advantages and disadvantages, are listed hereunder.

Casein

Casein glue is relatively cheap in first cost. It can be used on wood with a fairly wide range of moisture

content and will set firmly at a range of temperatures from well below to well above room temperature. It is satisfactory for use in dry locations, or where the moisture content of the wood will seldom be more than 20 per cent. Under such conditions, it can be expected to have a very long life and, therefore, is suitable for use in most types of heated buildings.

Casein glue is not recommended for use where structures or timbers will be submerged in water or exposed to the weather for any appreciable length of time. Excessive moisture will weaken the glue bond, and excessive humidity may encourage development of moulds which can destroy the bond. The use of toxic preservatives may slow or prevent the growth of fungi and bacteria, but the use of casein glue in very moist locations is not considered good practice.

This glue is more adaptable to thick glue lines than are most other adhesives. Even with inadequate gluing pressure or improper surfacing of the material, it will frequently give a good bond.

Urea-formaldehyde Resins

Urea glues are considerably more resistant to moisture than casein, and resist the effects of being soaked in cool water for appreciable periods. They are recommended for temporary structures which will be subjected to soaking or to severe weathering. Prolonged submersion in water, especially salt water, is not recommended, nor is prolonged exposure to conditions of high temperature and high humidity.

Urea resins are relatively cheap in first cost and will cure at from room (70°F). to much higher temperatures. The rate of curing is greatly accelerated at higher temperatures and consequently the useful pot-life of the glue may be considerably reduced in very hot weather. Thick glue lines should be avoided whenever possible: when this cannot be done, special gap-filling urea resins should be employed.

Phenol-formaldehyde Resins

Straight phenol-formaldehyde resin glues are not generally suitable for glued, laminated construction, because of the high temperatures required to cure the glues and the inherent difficulties of applying heat to the inner glue lines of large structural sections. However, these glues are extremely water-resistant, mould-resistant, and durable over very long periods of time. They are quite suitable for use in bonding sheets of plywood (which is cured by hot-pressing) and are recommended for those constructions which combine plywood with solid or laminated structural timber.

Resorcinol-phenol-formaldehyde Resins

These glues can be cured at temperatures between room temperature and the curing temperature of most phenol-formaldehyde resins. They possess the same qualities of durability and water-resistance as do the phenolic glues, but have the disadvantage of higher cost.

Curing is accomplished by one of several methods. The structural member may be glued, clamped, and placed in a kiln capable of producing the required curing temperature. The relative humidity of the air inside the kiln is maintained at a sufficiently high level to prevent too much loss of moisture by the wood. The length of time in the kiln must include the initial heating-up time, as well as the required curing time, and a cooling-down period.

Radio-frequency dielectric heating may be employed to cure the glue in sizeable structural timbers. By this method, heating of the inner glue lines is accomplished in considerably less time than is required in a kiln.

If the finished product is to be treated with preservative by some method such as the empty-cell, creosote process, the final curing may be accomplished while the timber is immersed in the heated creosote solution.

Table 33 summarizes useful information concerning the chief types of glue employed in glued, laminated construction. The data shown are necessarily quite general in character. In all cases, the advice of the glue manufacturer with respect to mixing, spreading, and curing should be followed.

Preparation of Gluing Surfaces

Laminations should be dressed to a uniform thickness, to avoid thick glue lines or unglued gaps. The pressure applied to the timber during gluing will, to some extent, provide close contact between laminations with surface irregularities. However, such irregularities should be kept to a minimum, since hollows in adjacent boards can only be brought together by excessive clamping pressure which, in turn, may result in crushing the wood fibres in adjacent areas.

A series of shear tests, undertaken to determine the relative gluability of various surface conditions

GENERAL INFORMATION FOR CHIEF TYPES OF GLUE USED IN LAMINATED CONSTRUCTION

TABLE 33

	Casein	Urea-formaldehyde	Phenol-formaldehyde	Resorcinol-phenol-formaldehyde
Water-resistance	Fair	Good	Very good	Very good
Durability	Very good	Fair	Very good	Very good
Glue spread, pounds per 1,000 sq.ft. glued surface	60-80	35-50	35-50	35-50
Curing temperature	40°F.	70°-260°F.	280°-320°F.	72°-200°F.
Clamping period	4 hrs. at 70°F.	4 hrs. at 75°F.	—	—
Pot life	6-8 hrs. at 70°F.	4-6 hrs. at 70°F.	Indefinite	2-8 hours at 75°F.
Storage life	1 yr.	Powdered glues 1 yr. liquid glues 4-6 months	1 yr.	4-6 months at 70°F.
Moisture content of wood, per cent	4-15	7-12	4-6	6-15

SHEAR TESTS SHOWING GLUABILITY UNDER VARIOUS SURFACE CONDITIONS

TABLE 34

Adhesive	Surface Conditions	Spruce to Spruce	Spruce to Pine	Spruce to Fir	Pine to Pine	Pine to Fir	Fir to Fir
		p.s.i.	p.s.i.	p.s.i.	p.s.i.	p.s.i.	p.s.i.
Casein	Planed to Planed	1050	1064	1045	1287	1393	1437
	Planed to Sawn	902	—	—	1343	—	1187
	Sawn to Sawn	811	—	—	1192	—	1108
Urea-formaldehyde resin	Planed to Planed	744	1205	983	1201	1014	1226
	Planed to Sawn	760	—	—	1221	—	1082
	Sawn to Sawn	768	—	—	1182	—	876

in three species of wood, yielded the results shown in Table 34.

Three species, spruce, pine, and Douglas fir were glued to each other in various combinations. Planed surfaces were glued to planed surfaces, planed surfaces to sawn surfaces, and sawn surfaces to sawn surfaces. The planing was done on a cabinet planer and the sawing carefully done by a circular table saw. The glued specimens were tested in shear parallel to the glue-line, to determine the relative strengths of the various methods of surfacing.

As might be anticipated, the planed-to-planed surfaces generally developed the strongest glue bonds, and the sawn-to-sawn surfaces the weakest. Planed surfaces are preferable, therefore, for glued lamination construction. It is recommended that the final surfacing be performed on a cabinet planer with accurately set and straight-ground knives. The thickness of the finished board, immediately prior to assembly, should not vary from the mean at any point by more than ± 0.01 inch.

Sanding to improve the gluability of the wood surface is not recommended, except in cases where dull planer knives may have glazed the surface of the wood. If the planer knives are kept sharp, and are accurately ground and set, no advantage is gained by sanding the surface after planing.

Moisture Content of Lumber

Green lumber should not be used for glued, laminated construction. The lumber should be kiln-dried or air-seasoned to a suitable moisture content,

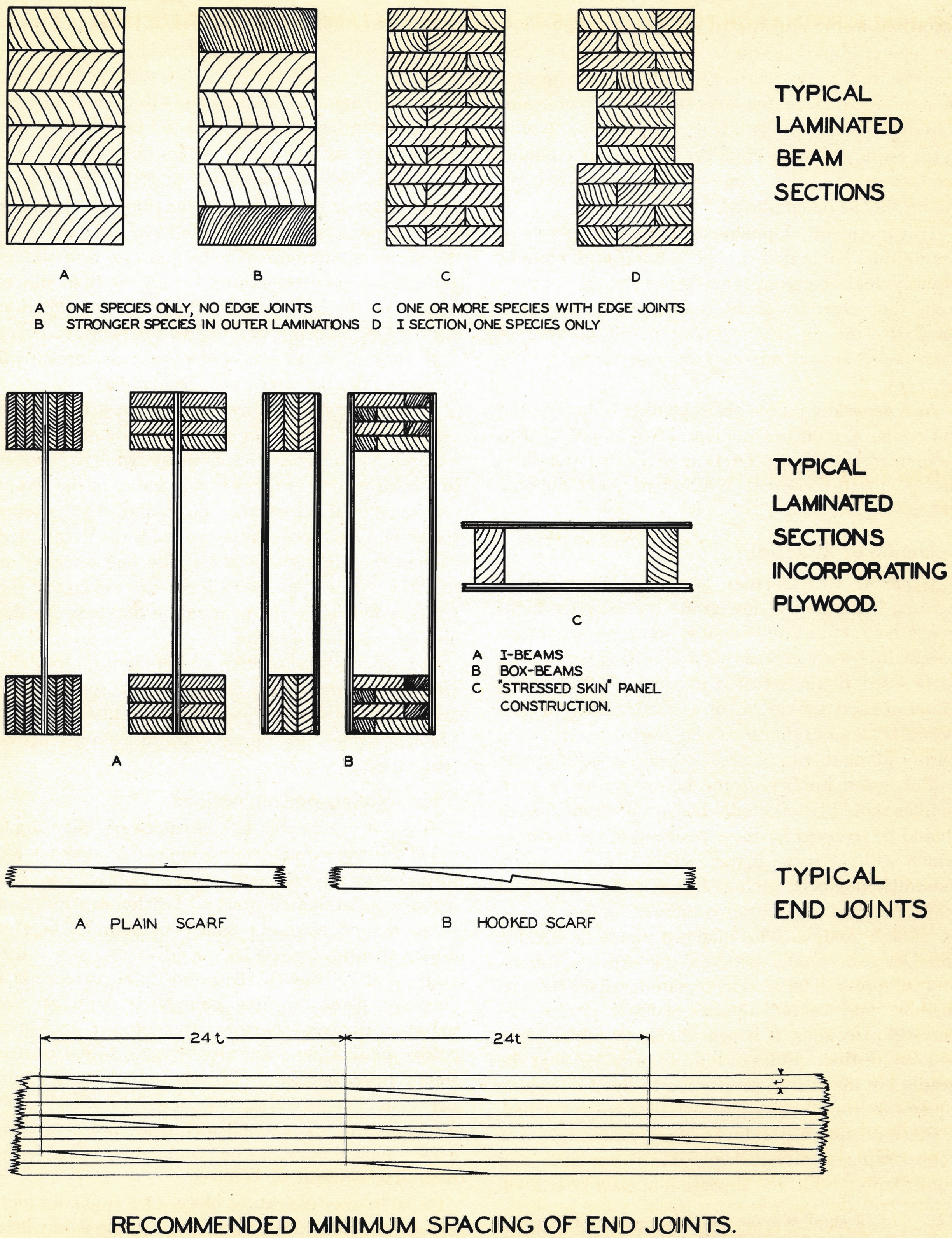


FIGURE 45.—Types of Laminated Construction.

according to the anticipated service conditions and the type of glue that will be used. Unless the glue manufacturer's instructions conflict, the lumber should be dried to the expected service moisture content before assembly. If it is not feasible to glue at the estimated mean equilibrium moisture content, the nearest moisture content conducive to good gluing should be employed.

To prevent development of secondary stresses in the finished laminated timber, the moisture content of individual boards or laminations should not vary from the mean by more than $\pm$ 2½ per cent. Similarly, the moisture content in all portions of each board should not vary by more than $\pm$ 2½ per cent.

As a general guide to the seasoning of laminating materials, a moisture content of 8-10 per cent is recommended for the interiors of heated buildings and a moisture content of 12-15 per cent for outdoors.

Selection of Material

While it is true that laminated construction permits utilization of low-grade material for high-strength structural timbers, it is necessary to exercise considerable care in selecting and sorting the lumber to be used in the finished product. Some of the material used should be of a good grade. When possible, material that has been graded as structural joist or plank should be used; otherwise, good grades of dimension lumber or the better grades of yard lumber should be selected. The better-grade boards should be reserved for those positions in the member which will carry the highest stress. In the case of flexural* members, such as beams and stringers, at least one-third of the total volume of lumber should be of high quality. This material should be divided more or less equally between the extreme tension and compression faces. The remainder of the flexural member may contain lumber of lower grades. In very deep sections, it is practicable to utilize three or more distinct grades of lumber provided that the grades are lowered in proportion to the diminishing stresses as the neutral axis of the section is approached.

Since existing methods of grading do not take into consideration all factors involved in glued, laminated construction, a further inspection of each board will be necessary before it is allotted to its proper place in the assembly. When undertaking this inspection, it is well to remember that defects such as knots and cross-grain tend to weaken the lamination in tension or compression parallel to the lamination; and that defects such as splits, shakes, and checks tend to weaken the structural member in shear, particularly as the angle between the split and the shear plane approaches zero. Knots have little effect on the shearing strength of a lamination, and shakes and checks may sometimes be tolerated in places where the direct stresses are high but the shearing stresses low. Such a practice will depend, in every case, on the orientation of the shake or check with respect to the glue-lines and shear planes.

It is not good practice to mix flat-grained and edge-grained lumber in the same assembly. The expansion and contraction of wood owing to changes in moisture content differ considerably in the radial and tangential directions. To minimize the occurrence of secondary stresses within the laminated timber, the lumber should fall into one category or the other. The angle of 45 degrees to the face of the lamination is taken as the dividing line between flat and edge-grained lumber.

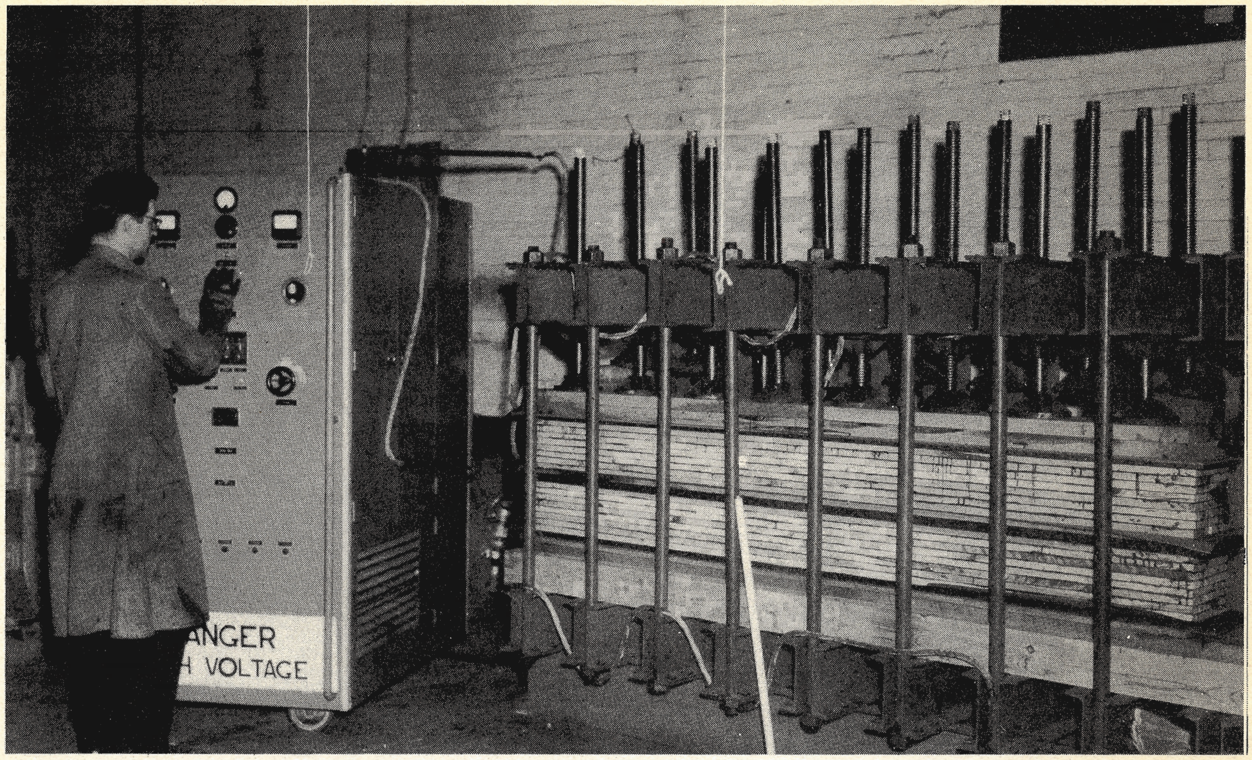
It is generally considered good practice, especially with species noted for having weak spring-wood layers, to employ edge-grained lumber and to "herring-bone" the annual rings in each successive lamination.

Edge-jointing of Laminations

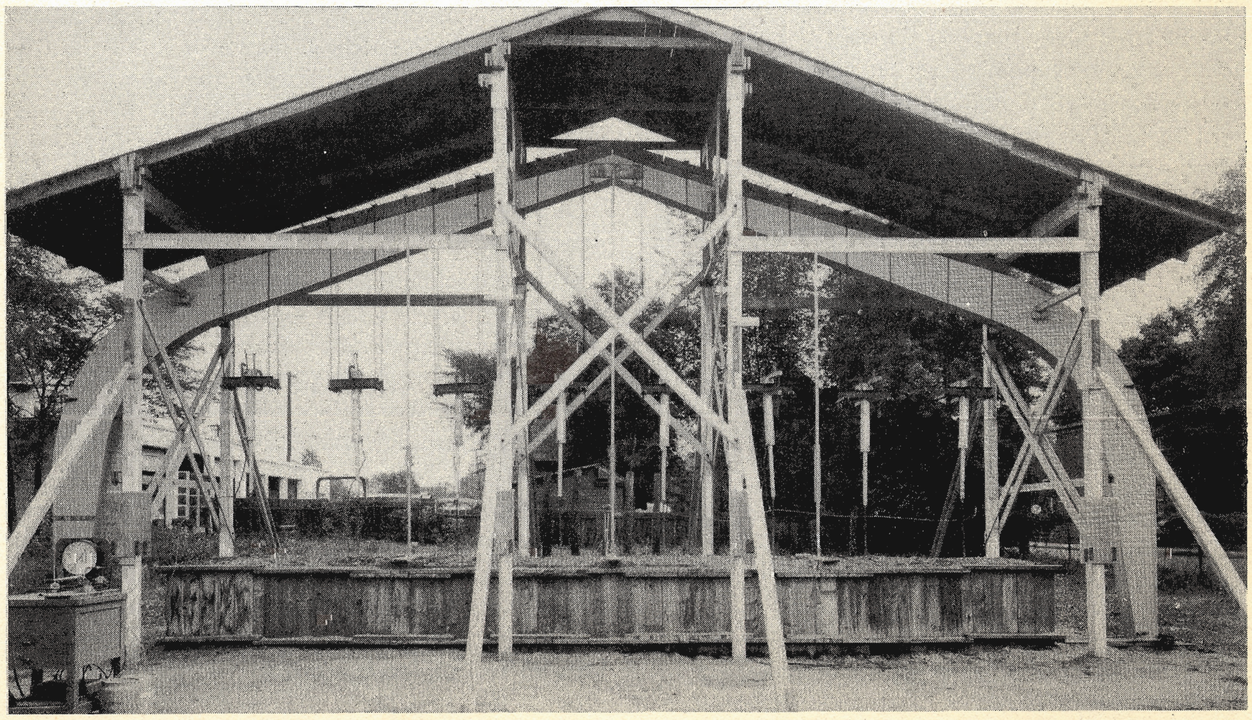
It is not practicable to construct very large laminated timbers without employing two or more boards to make up the required width of lamination. For instance, a laminated timber 13 inches in width can be fabricated by using boards of nominal 6- and 8-inch widths, dressed on the edges to a net width of 5½ and 7½ inches. To avoid the occurrence of a cleavage plane running completely through the member, the edge joints are staggered in each successive lamination. For this reason, 8-inch boards should never be used exclusively to build up a member 15 inches in width; it is better to use 10- and 6-inch boards. If 10-inch widths are not available, a 14½-inch timber can be obtained by using 6-, 6- and 4-inch boards.

A better product can be obtained if timbers which will be exposed to the weather or situated in water or earth are constructed of laminations which have

*The term 'flexural' is applied to structural members which are subjected primarily to forces tending to produce bending, rather than crushing.



Bonding Glued, Laminated Ties by Dielectric Heating,



Glued, Laminated Arch, 47-foot Span, being Test-loaded to Destruction.
LAMINATED CONSTRUCTION.

previously been edge-jointed. This technique need not always be followed if the structural member is designed for use inside a heated building.

The recommended edge-gluing procedure is to plane the edges of the boards and to give the faces a rough surfacing only. Glue is spread on the edges and pressure is applied by clamps until the glue has set sufficiently to permit the clamps to be removed. With resin glues, this process can be speeded by employing radio-frequency dielectric heating. After the glue has cured sufficiently to allow the laminations to be handled, the squeezed-out glue is scraped off and the two faces are given a final surfacing in a cabinet planer.

End-jointing of Laminations

Except in the case of very short laminated timbers, it will always be necessary to end-joint lumber to make up laminations of the required length. A number of end joints of various types have been devised. They include such designs as the acme-thread scarf, the Onsrud joint, the serrated scarf, the finger joint, and the plain and hooked scarf joints.

Some of these end joints require the use of special tools for shaping the ends of the boards. The only type which can be employed without the use of special equipment is the plain scarf. This joint is made simply by planing the adjacent ends of the lamination to a flat slope of 1 in 12, 1 in 10, 1 in 8, or 1 in 5. The hooked scarf is very similar to the plain scarf, except that it incorporates a hook or ridge which serves the purpose of positioning the glue surfaces and facilitating the alignment during pressing. A properly made hooked scarf requires the use of special jigs and is, therefore, not practicable in smaller woodworking shops.

Tests have shown that the plain scarf joint gives quite satisfactory results and it is not necessary, therefore, to employ more complicated forms of joint. The steeper the slope of the plain scarf, the weaker will be the glued joint. If the laminations are considered as acting in tension, the following table gives the approximate strengths of plain scarf joints of various slopes, expressed as a percentage of the strength of a jointless lamination.

EFFICIENCY OF PLAIN SCARF JOINTS

Slope	Efficiency	Slope	Efficiency
1:12	90%	1:8	80%
1:10	85%	1:5	65%

If the scarf end-joint is located on the extreme tension face of a beam at the point of maximum bending moment, it will be necessary to employ a plain scarf with a slope of 1 in 12. However, if the joint is fairly close to the neutral axis of the beam, a steeper slope may be used. Steeper slopes may also be used on the compression side of a beam, provided necessary care is exercised to prevent the beam being erected upside down. Columns, also, may be constructed with scarf joints with slopes steeper than 1 in 12. Exploratory tests have indicated that this slope may be 1 in 5 without causing appreciable reduction in the over-all strength, as compared to columns with jointless laminations.

End-joints should be glued before the laminations are assembled in the member. This is the only way of ensuring an end-joint of adequate strength. One method is to glue several end-joints and apply gluing pressure to the stacked laminations, separated by paper, by means of a single screw clamp or set of clamps. Perfect alignment of the two sections of the lamination is very important when the end-joint is made. It is also important that the surfaces of plain scarf joints be positioned accurately so as to ensure a continuous plane surface of the lamination. This can best be accomplished by allowing the upper surface to ride a little too high on the lower surface so that the gluing pressure will force the assembly into proper alignment. It is also advisable to use some mechanical means of fastening the two sections of each lamination together, so that the adjustment will be maintained until the clamping pressure has been applied.

When the clamps have been removed from a batch of end-joints, it will only be necessary to rip off the paper separating one lamination from another and to scrape the squeezed-out glue from the vicinity of the joint. If imperfect surface alignment is detected at this time, it can be corrected by use of a hand plane or sander.

The laminations should be arranged in the member so that the centre-to-centre spacing of scarf-joints in adjacent laminations is at least 24 times the thickness of a lamination. If possible, end-joints should be kept away from locations of maximum tension stress in any member, as well as from locations where it is necessary to bend the lamination around a curve of sharp radius.

Butt joints are not a recommended form of end-

joint for laminated construction. They cannot transmit tension stress and are very inefficient in transmitting compression stress. They may be used, with negligible decrease in efficiency, in that one place in a laminated beam where the stresses in tension and compression are practically zero. However, if the beam is intended for exterior use, butt joints will be an inherent cause of weakness, because through them moisture and fungous spores can obtain easy entry into the interior of the beam.

Application of Glue

Glue may be applied by hand with a brush or by some form of mechanical spreader: spreaders which will apply an even coating of glue to one or both faces at the same time are available. Generally, a light coating of glue applied to both faces of each lamination is better than a heavy coating applied to one face only. Either method will produce satisfactory results, provided there is enough liquid glue to wet completely both surfaces to be joined.

Assembly Time

Allowable time between the spreading of the glue and application of gluing pressure will vary with the type of glue, temperature of the surrounding air, and thickness of the glue spread. The assembly period preceding the application of pressure should be kept to a minimum. The essential point is that the glue shall still be tacky when pressure is applied.

Gluing Pressure

The pressure required to obtain good bonds varies with the species and type of glue employed. Most resin glues require higher gluing pressures than does casein, which also possesses good gap-filling properties. Hardwood species require higher gluing pressures than softwoods. The accuracy with which the laminations are finished is an important factor. If each lamination is planed to a uniform thickness, little pressure is required to bring all surfaces into close contact. However, when slight irregularities exist (and this is more than likely), considerable pressure is required to compress the wood fibres at the high spots and thus bring the low spots into contact with each other.

Suggested minimum gluing pressures are shown in the following table:

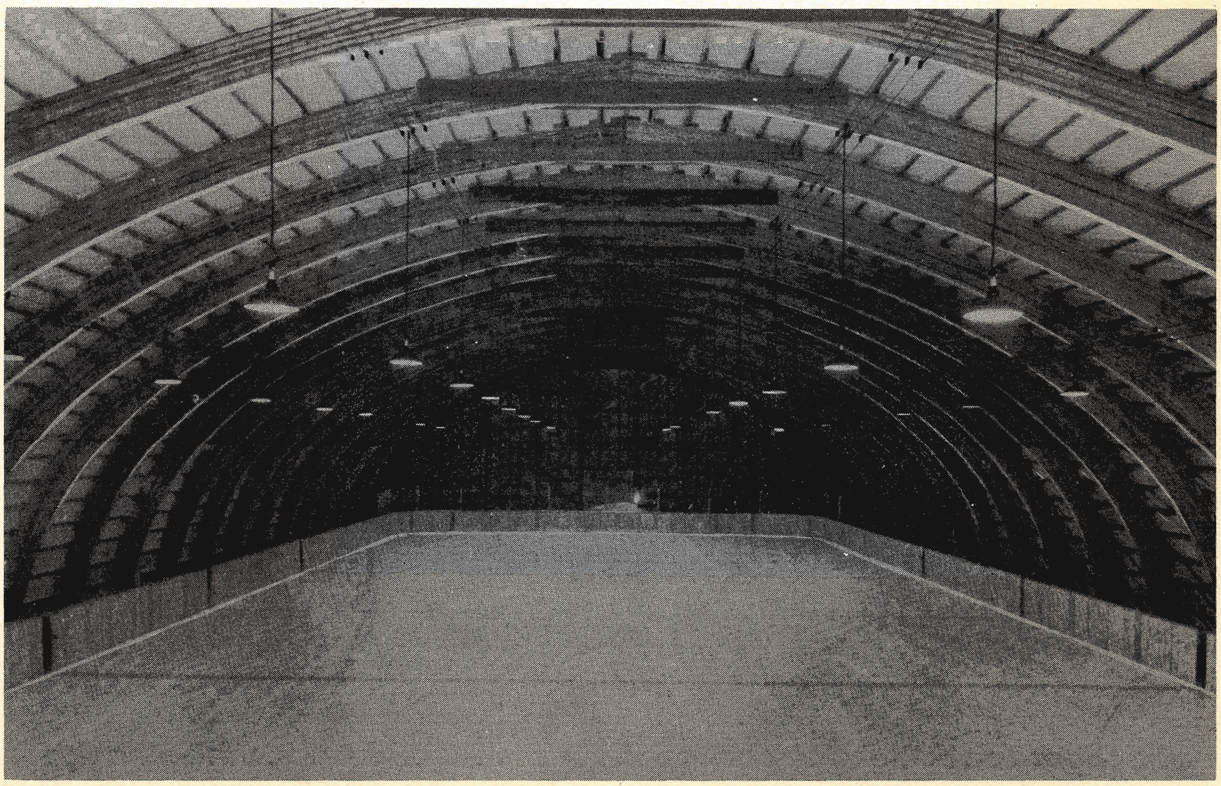


PLATE 100.—Glued, Laminated, Wooden Arches. Memorial Arena, Densmore, Sask.

	Softwoods p.s.i.	*Hardwoods* p.s.i.
Casein	100	150
Resin glues	150	200

It is recommended that pressure be applied by screw or hydraulic clamps: it should be applied as quickly as possible after assembling the laminations, either by working from the centre toward the ends, or by working from one end to the other. The pressure should be left on until the glue bond has attained sufficient strength to resist any tendency of the laminations to spring apart when it is removed. This tendency will be greater with curved sections or with warped, improperly planed laminations in straight timbers.

Nailing is not so satisfactory as clamping for applying gluing pressure. The results are likely to be more erratic, because of the small force developed by each nail. However, good results are sometimes obtainable, particularly with casein glue and nails at short spacings. It is recommended that at least one nail be used for each 15 square inches of glued area and that the length of nail should be at least equal to 2½ times the thickness of one lamination.

Types of Section

The most common section for glued laminated beams is the rectangle. This lends itself to the use of low-grade material near the neutral axis of the beam, the better-grade material being reserved for the extreme stresses at the tension and compression faces. I- or box-sections will sometimes be more economical for very long spans.

The simplest form of I-section is one in which the web and flanges are both constructed of laminated lumber with parallel laminations. The width of the laminations in the web section is made considerably less than that of the flange laminations, but nevertheless of sufficient width to resist the longitudinal shear at the neutral axis of the beam. The longitudinal shear stress can be computed by the following formula:

$$v = \frac{VQ}{Ib}$$

where v is the longitudinal shear stress in p.s.i.;
where V is the vertical shear in pounds;
where Q is the first moment of area of the section above the shear plane, in inches^3;
where I is the moment of inertia of the cross-section of the beam in inches^4;
where b is the width of the shear plane in inches.

For rectangular sections, the value of the shear stress at the neutral axis reduces to the following:

$$v = \frac{3V}{2A}$$

where A is the area of the section in square inches.

I-beams and box-beams can also be constructed by using plywood for the webs and laminated lumber for the flanges. Plywood used with the plies vertical is able to develop much higher shear stresses than horizontally laminated lumber. The safe shear stress for plywood webs varies with the species and grade of plywood used. Generally, the working shear stress should not exceed two or three times the commonly accepted working shear stresses for the species. If commercial grades of plywood are used, the factor of two may be applied, and if special structural plywood is used, the factor of three.

In addition to the horizontal and vertical shear stresses developed in the plywood webs of I-beams and box-beams, "rolling shear" is also developed between the plywood and the flanges and between the plies of the plywood in the immediate vicinity of the flanges. The safe stress in rolling shear should not exceed one-half of the safe longitudinal shear stress for the species.

From the standpoint of strength, it is better to arrange the plywood web with the grain of the plies at 45 degrees to the axis of the beam. However, this tends to be a wasteful practice, because of the necessity of cutting off the corners of the plywood panels. The next best arrangement is one in which the grain of the face plies is at 90 degrees to the axis of the beam, i.e., vertical in a horizontal beam. This gives a web with greater resistance to buckling in the vertical plane.

In the design of all I-beams and box-beams with plywood webs, provision should be made for stiffeners at all points of concentrated loading, and also at intermediate points along the span. The stiffeners at the end supports should fit snugly between the flanges, and should be as wide as the flange or flanges as the case may be. The area of such stiffeners should be sufficient to develop the end reaction with a stress not exceeding the safe working stress in compression perpendicular to the grain, for the species of which the flanges are constructed. Their function

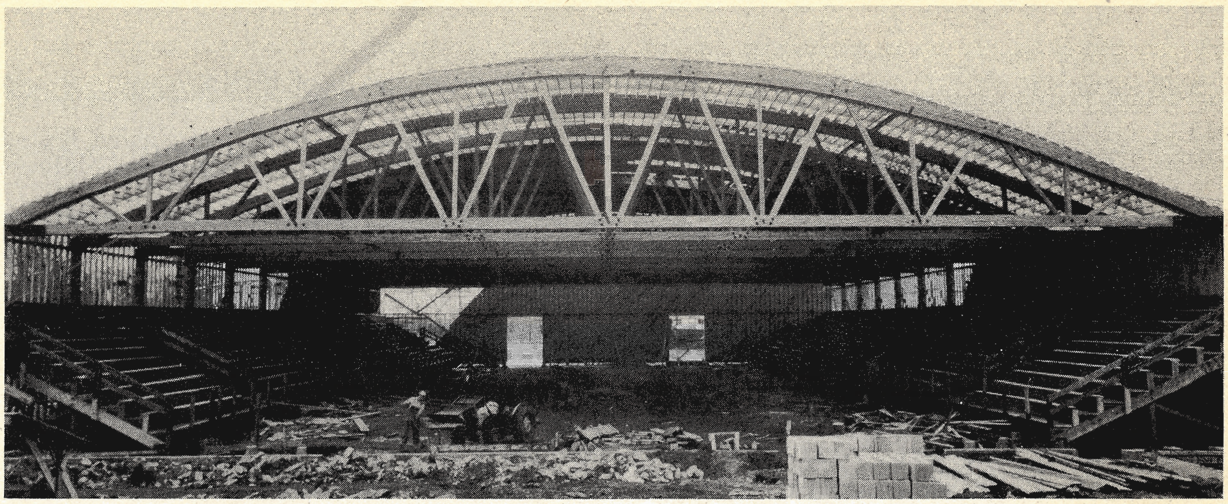


PLATE 101.—Timber Bowstring Trusses with Glued, Laminated Top and Bottom Chords. Span 128 ft. Memorial Arena, Smiths Falls, Ont.

is to distribute the end reaction stresses to the beam as a whole and not to the bottom flange alone. The same principle should be applied to the design of stiffeners at all other points in the beam where concentrated loads are applied. Intermediate stiffeners should be placed at intervals not exceeding twice the clear depth of the web. These stiffeners need not be designed to provide full bearing against the flanges. In the case of box-beams, small air-holes should be drilled through the centre of all stiffeners which completely fill the rectangle between the webs and flanges. This will provide a certain degree of ventilation for the interior of the beam and help avoid unequal distribution of moisture in the wood.

Arches and Curved Truss Chords

In the construction of curved laminated timbers, such as arches and bowstring truss chords, the individual laminations must be bent around a form, and this will induce an initial stress in both faces of each lamination. If the radius of curvature is relatively large, such as in a bowstring truss, and if the laminations are relatively thin, this stress will be very small and may sometimes be neglected entirely. However, in the construction of very flat arches, where the radius of curvature at the haunch is quite sharp, the initial bending stresses at that point should be taken into account in the design.

Within the proportional limit of the material, the stress induced by bending can be calculated by the following formula:

$$f = \frac{E\,t}{2R}$$

where f is the flexural stress in p.s.i.;
where E is the modulus of elasticity of the material, as determined by short-term loading, in p.s.i.;
where t is the thickness of the lamination in inches;
where R is the radius of curvature of the *neutral axis* of the lamination in inches.

If the stress thus computed is above the proportional limit stress for the species used (See Appendix Table 2), then it is apparent that the stress may have exceeded the proportional limit stress and the figure obtained is unreliable. If account is taken of the variability of the species, the values obtained should not be considered reliable if they exceed 75 per cent of the values listed in the tables.

Laminations which are bent to a very sharp radius should be designed with a reduced working stress. Wilson* suggests that the following factor be employed to reduce the working stress in accordance with the curvature of the member.

$$1 - 2000\left(\frac{t}{R}\right)^2$$

where t is the thickness of the lamination in inches, and where R is the radius of curvature in inches.

When it is necessary to bend laminations around a curve of extremely sharp radius, it may sometimes be necessary to subject the lumber to a steaming treatment to facilitate bending without breakage. This procedure is not recommended and, whenever possible, the radius should be increased or the lamination thickness reduced to facilitate bending in the cold state.

*Wilson, T. R. C., "The Glued, Laminated Wooden Arch", Technical Bulletin 691, 1939. U.S. Dept. of Agri., Washington, D.C.

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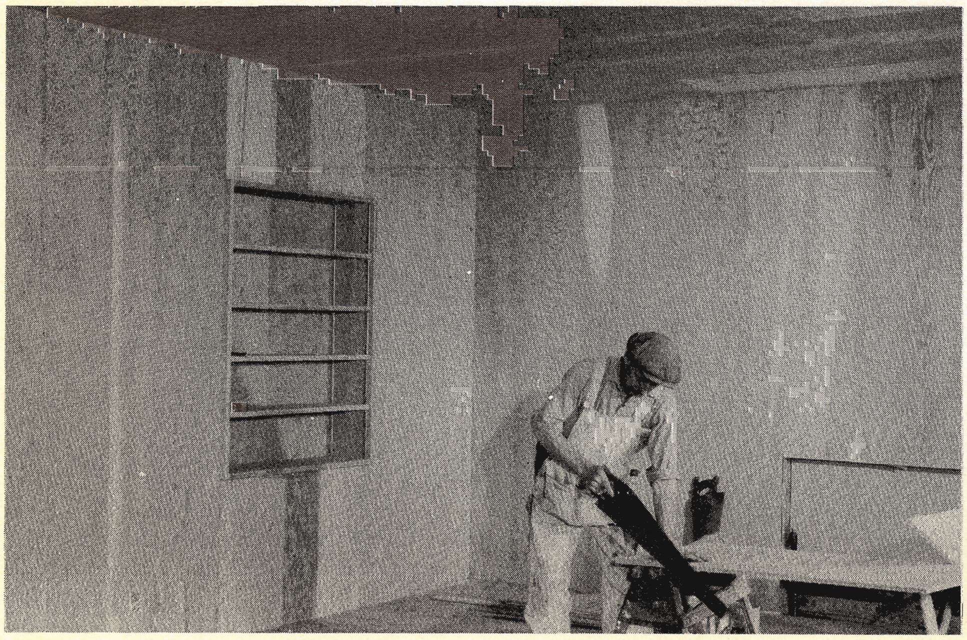


Plywood as an Interior Finish is both Durable and Beautiful.

CHAPTER 12

SHIPPING CONTAINERS

by W. BUTTERWORTH

THE designing of shipping containers is largely a problem of compromise. A container is only a means to an end, and generally has only scrap value after it has reached its destination. The cheapest container that will effectively protect goods in transit from vibration, road shocks, and rough handling, and that will also give a degree of security against pilferage, damp, rodents, etc., is the most desirable container for the purpose.

Damaged or deficient shipments are unsatisfactory to the buyer. Containers failing to protect goods in shipment are unsatisfactory to the shipper. The nature of the damage sustained and the part of the container that failed in its function will suggest necessary modifications. Whenever more costly construction is involved, it is well to consider whether the added expenditure for containers will be balanced by a reduction in damage to the contents.

Many containers are heavier and bulkier than is necessary. These are factors which in many cases make it worth while to give considerable thought to careful redesign, which experience shows may reduce size and weight materially. Railroads base their charges on weight, though there is a minimum weight charged for in carload lots. Cargo space on board ship is charged for by volume, regardless of the weight, except for very dense commodities. A small reduction in one dimension of a box may enable an extra row or tier of boxes to be loaded. Some countries levy import duties on the gross weight. Apart from these considerations, any reduction of size and weight will make a container easier to handle.

While good appearance is not as essential in a container as it is in a piece of cabinet-work, it is worth remembering that a functional beauty arises from a proper proportioning of the parts and fitness to perform the required service. A container of poor appearance is often unsatisfactory in service.

TYPES OF CONTAINERS

Wooden Boxes and Crates

These are used for heavy, bulky, or fragile articles, or for those requiring a greater degree of protection than can be provided by lighter and cheaper containers (1, 2, 3). Wooden boxes and crates are especially suitable for export service. There are nine main types of wooden box (Fig. 46) and an infinite variety of wooden crates. The nine types of box provide a range thoroughly satisfactory for loads of different densities and varying susceptibility to damage; some types may be further reinforced by battens. Certain items are more prone than others to damage the boxes that hold them. Welding rods, which are apt to slide longitudinally and hammer out the end of a box, require a stouter box than would a single rigid article of the same weight.

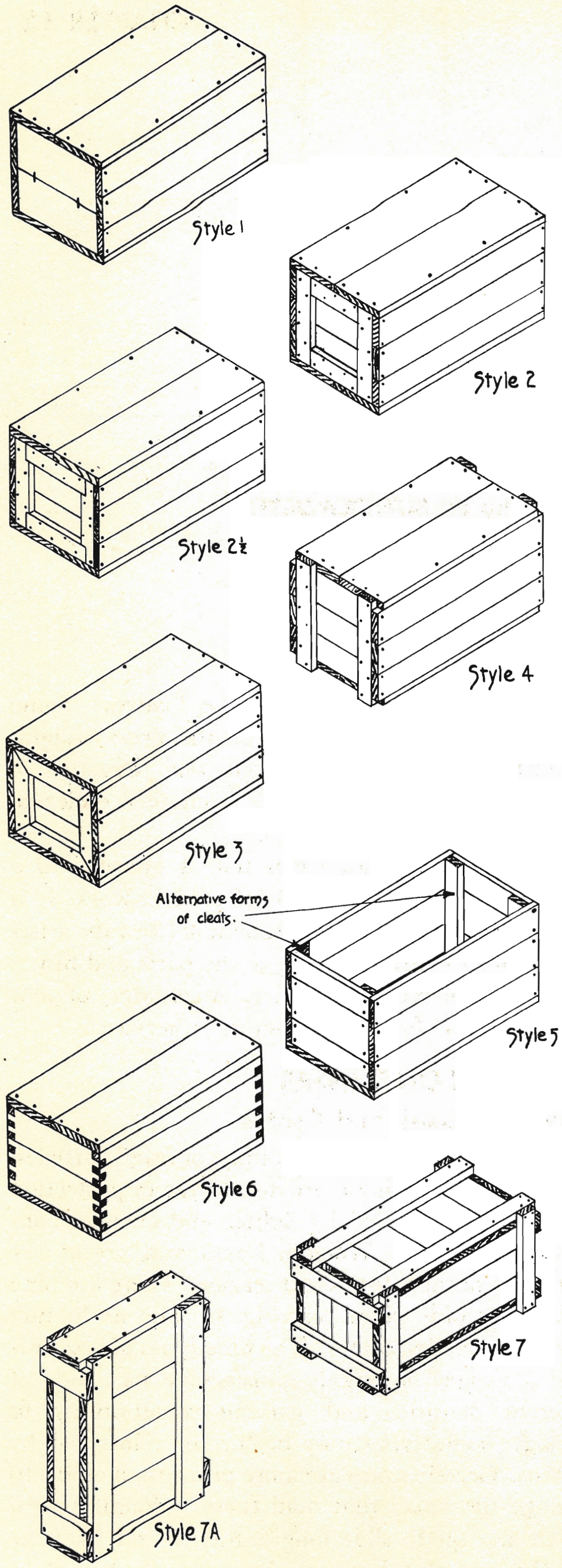


FIGURE 46.—Types of Wooden Boxes.

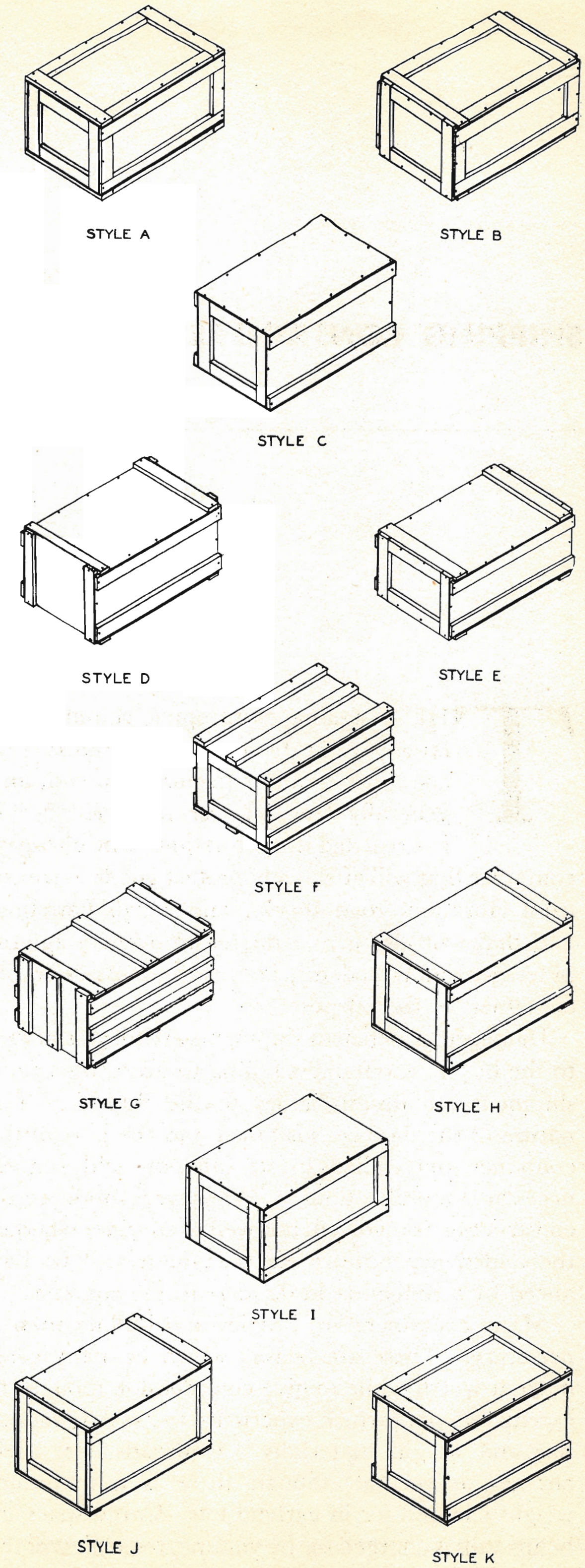


FIGURE 47.—Types of Plywood Boxes.

When a type suitable to the nature and weight of the load has been selected, appropriate specifications give the thickness of boards required for the parts and the size and number of nails required at each joint. The box can then be made to the size required to fit the contents, allowance being made for any internal packing required (see packing). Crates are largely used for special articles not convenient to pack in a box, such as automobile engines, machine tools, and stoves. The crate is designed to suit the article to be packed, particular care being taken to ensure that only those parts of the article designed to support its weight can come in contact with any part of the crate. Though a crate is essentially a skeleton construction, it may be sheathed with fibreboard, plywood, boards, etc., to keep out rain or moisture, or to prevent damage to the contents from objects passing between the members of the crate. There is no definite distinction between a fully sheathed crate and a heavily cleated and battened box.

Plywood Boxes

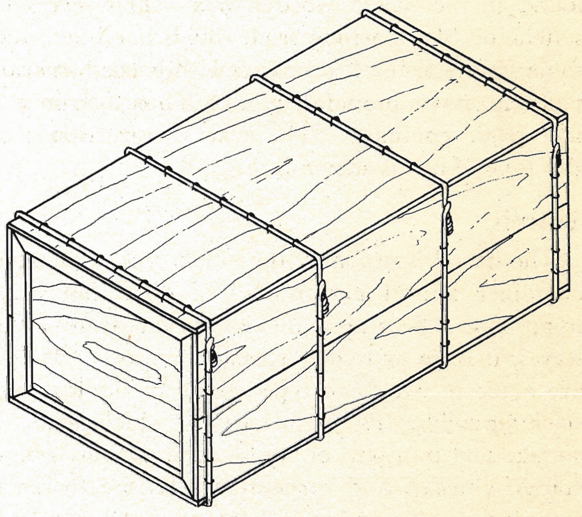
These are made from panels of plywood clinch-nailed or stapled to a wood frame (4). The panels are fastened together to make a box by nailing through a panel into the side grain of the frame of the adjacent panel; Fig. 47 shows typical styles of plywood boxes. Box-grade plywood is used for most purposes, as it has adequate strength. It is cheaper than the best grades of plywood, as it is made from the lower grades of veneer, and is not given a high finish. It is common practice in box plywood to make all plies the same thickness, so that all the veneer used can be taken from the same run. The best veneer is used for the face of the board, the second quality for the back, and the remainder is used for the core. The veneers are not taped before bonding, so that gaps or overlaps may occur. Vegetable glues or starch-extended urea resin glues are used for bonding. For export containers or other uses where much moisture may be encountered, a higher grade plywood bonded with water-resistant glues should be used, and when direct exposure to the weather is liable to occur, the adhesives used should be waterproof.

Plywood boxes are normally lighter and slightly smaller than equivalent wooden ones, and are especially valuable when a tight box is required. A plywood box is usually more rigid than a wooden box.

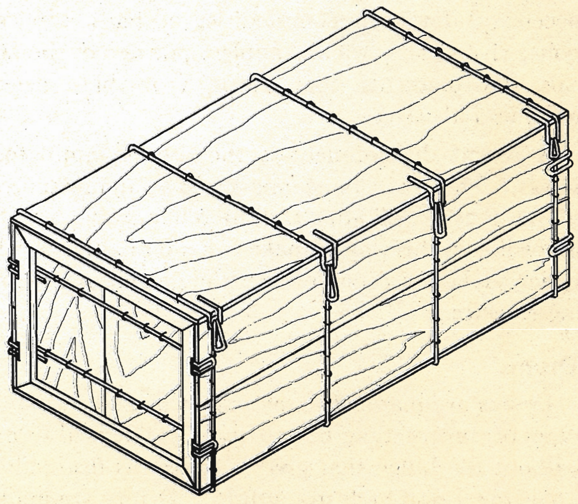
Wirebound Boxes, Baskets, Hampers

These useful containers are made of veneer. Birch is the most common Canadian species used, but the use of imported hardwoods is not uncommon (5).

Baskets and hampers, in various sizes, are made for marketing fruit and vegetables. The smaller baskets may have sides and bottoms formed from two pieces of folded veneer; larger sizes may have lumber or plywood bottoms. The top rims may be formed of bent strips of veneer to which the sides are stapled, or wooden hoops may be used. Other wood or veneer hoops, or steel rims, may be used to reinforce the sides of large hampers.



STYLE I. TWISTED WIRE CLOSURE



STYLE 3. LOOPED WIRE CLOSURE WITH LOOPED WIRE ENDS

FIGURE 48.—Wirebound Boxes.

A shipping container is made of veneer bound together with wires around the girth and across the ends of the box. Such containers are lighter than equivalent nailed wooden boxes and are shipped flat, thus economizing shipping and storage space. They are easily and quickly set up, packed, and closed, the girth wires used to give strength to the box providing the fastening. Containers of this type can be easily opened and re-used. If, on opening, the girth wires break where they were twisted together, short lengths of wire spliced on will make a new closure. These containers, by reason of their construction, possess a certain amount of give not found in the nailed wooden box. This serves to soften the blows arising from rough handling, and some fragile articles, if provided with good interior padding, travel more safely in such a box than in a more rigid container. The general construction of this type of box is shown in Fig. 48.

Barrels

The barrel is probably the oldest type of wooden container known and is still of great industrial importance. Because of the double curvature of the staves, it is an extremely strong container. Barrels are made in two basic types, tight for liquids, and slack for solids. The tight barrel is widely used for storage and transport of liquids such as beer, wines, spirits, vinegar, and turpentine. Its use for such purposes is so old and so widespread that a standard barrel is a legal unit of measure in many countries.

Slack barrels are widely used (with bag liner when necessary) for such commodities as nails, screws, bolts, rivets, fats, waxes, apples, powdered chemicals, dry pigments, soap chips, vegetables, dried milk, and abrasives.

A recent development is the use of laminated staves. These can be standardized in manufacture so that they are all alike and interchangeable, and it is possible in this way to make a demountable barrel, which makes for economies in storage and in returning empties.

Drums

Drums are made of many materials and in many types of construction, but all are of cylindrical form, without the bulge that gives a barrel its distinctive appearance and high strength (6). Drums are made of plywood, fibreboard, or paper, with ends of the same material or of metal, and the seams may be glued, stapled, or riveted. Fibreboard and paper drums may be formed either by wrapping the sheet round upon itself, or by winding a narrower strip round a mandrel in the form of a helix. The width of the strip is such that the angle of the helix is 45°. Plywood drums are usually large for bulk shipment of powdered or granular material. Fibreboard and paper drums are used, not only for bulk shipment of lighter commodities, but also in small sizes for packing in retail quantities.

Fibreboard Containers

These are folding-flap cartons made of either solid or corrugated fibreboard. They are light in weight, and constitute a very useful form of container for domestic shipment of a wide variety of commodities. While these containers are occasionally used for export shipments, they are not generally considered as satisfactory for this purpose as a wooden or plywood box.

Apart from the advantage of light weight, such containers are received from the box makers folded flat, so that they occupy little storage space until they are set up to be packed. The setting up, filling, and closing is a quick and easy operation. Gluing, stapling, or taping, alone or together, may be used in sealing the flaps.

Multi-wall Paper Bags

Two to six layers of various kinds of paper are used to make these bags, which are commonly used for loads up to 100 lbs., and are suitable for shipment or retail sales of almost all powdered or granular materials. The layers are not fastened together, but fit snugly one within the other. Either top, or bottom, or both, may be closed by folding to box form and gluing, or by sewing through the walls of the bag. For ease of filling, a tucked-in tube of creped kraft paper is often provided in one bottom corner. The bag is completely closed while empty, except for this tube, which forms a valve. The bag is filled through this valve while upside down, and then turned right side up, when the weight of the contents seals the bag.

Materials used are largely kraft and creped kraft paper, with various waterproof sheeting materials for moisture barriers, if required; these are generally asphalt kraft laminated paper or waxed kraft. Burlap may be used for the outer layer to protect the inner layers against risk of snagging.

Pallets

A pallet is a type of platform so designed as to serve three purposes:

a. To assemble in one unit a number of items packed in smaller containers.
b. To permit assembled units to be stacked for storage or transportation without placing excessive loads on the smaller individual containers.
c. To permit ready lifting and handling, either as units or in groups, by mechanical handlers.

The most desirable design is that in which the structural members are so arranged as to permit the bars of a fork-lift truck to enter from any of the four sides. Although pallets have been constructed in a variety of sizes, the advantages of standardization have long been realized, and at the time of writing two standard sizes—40″ by 32″ and 48″ by 40″—have been adopted; it seems likely that the latter size will ultimately be the one in general use.

As containers, unless very heavy and stable, must be strapped to the pallets, pilferage is much less likely than in the case of individual containers. Risk of damage is also lessened, as there is a greater tendency to handle a composite load carefully.

Pallets greatly speed handling and loading, thus reducing labour costs and cutting down waiting time for valuable equipment in docks or freight yards.

When used for irregular containers or for high stacking in warehouses of containers not designed with the necessary compression strength, a pallet may have a superstructure consisting of uprights with a skeleton top decking suitably braced to support the load of other pallets on top, without transferring any load to the containers on the pallet base.

FASTENERS

Nails, Staples, Screws, Bolts

Nails are the most commonly used fasteners for all wood, or plywood, boxes and crates. Staples are convenient for light duty, especially in the making of fruit baskets, hampers, and fibreboard containers. Screws are occasionally used for box lids when it is known that the lid will have to be removed and replaced for some purpose such as customs inspection, as a screw can be redriven without much loss of holding power, especially in the harder woods, whereas a redriven nail is practically useless. Bolts are useful in joining the main frames of the heaviest crates and for fastening heavy objects such as engines or machinery to the base of the crate, but have little other use in box construction (7, 8).

Box nails are slightly thinner than common nails of the same length; the resulting flexibility of the box nail makes it less likely to be worked loose by twisting of the container, which may be caused by handling or by the rolling of ships. The thinner nails are also less likely to cause splitting when driven into the edge of the board. Clinch nails are used to fasten cleats and battens to panels. These are slightly thicker than common nails of the same length and are never driven into edges of boards. The points are always clinched to prevent their working loose. Etched or cement-coated nails are useful, as they have a markedly higher holding power than bright

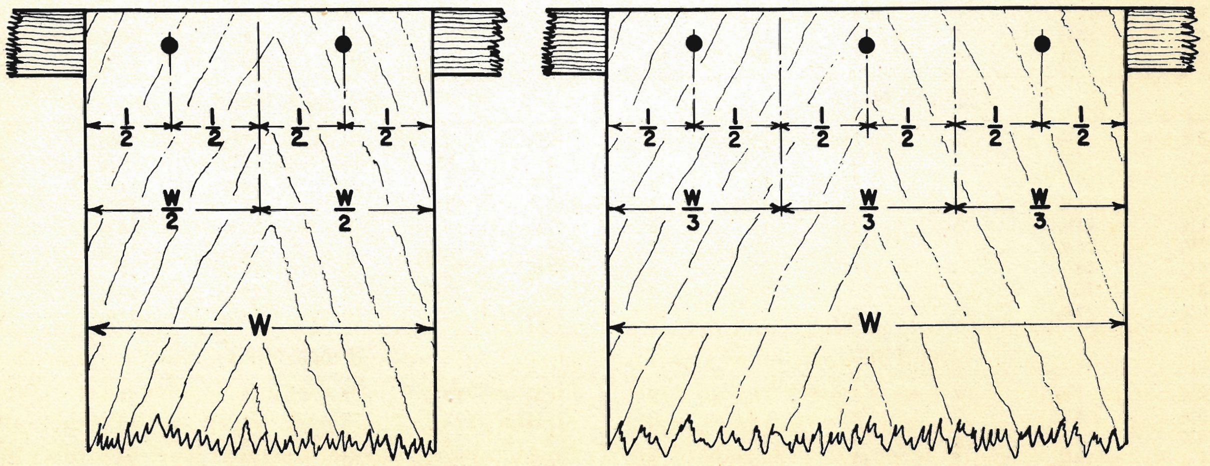


Figure 49.—Proper Spacing of Nails.

nails; however, in the case of cement-coated nails this improvement is not permanent, but begins to decline after five or six weeks; the maximum advantage of cement-coated nails can only be realized if the box is nailed up immediately before shipment, although they are always better than bright nails (1). See Fig. 49 and Tables 35 and 36 for proper spacing of nails.

Strapping

Boxes of all kinds can be greatly strengthened at very little cost in time or materials by strapping with either steel tape or with wire, which can be wrapped round the box, drawn tight by one of several tensioning devices, and fastened (9, 10). Steel tape is secured by placing a short bent clip over the tape where it laps on itself and cramping clip and straps tightly together with a special tool. Some tensioning tools are provided with means for placing the clip, closing it, and cutting off the free end of the tape by one movement of a lever. Wire straining tools are of two types; one has a device for twisting straight wire so as to form a seal, while the other uses a special wire with, on one end, a preformed lock

TABLE 35

SPACING OF NAILS OF DIFFERENT SIZES AS DRIVEN INTO SIDE OR END GRAINS

Size of Nail in Inches	Spacing	
	Side Grain	End Grain
	inches	inches
2 or less	2	1¾
2¼	2¼	2
2½	2½	2¼
2¾	2¾	2½
3	3	2¾
3¼	3¼	3
3½	3½	3¼

TABLE 36

NUMBER OF CANADIAN-MANUFACTURED, IMPERIAL GAUGE, CEMENT-COATED NAILS TO BE USED FOR VARIOUS WIDTHS OF SIDES OF BOXES:

1¼, 1½, 1¾ or 2-inch Nails						2¼-inch Nails					
Nailing into End Grain			Nailing into Side Grain			Nailing into End Grain			Nailing into Side Grain		
When the Width of Part is		No. of Nails	When the Width of Part is		No. of Nails	When the Width of Part is		No. of Nails	When the Width of Part is		No. of Nails
Over	Up to and Including		Over	Up to and Including		Over	Up to and Including		Over	Up to and Including	
In.	In.		In.	In.		In.	In.		In.	In.	
2½	3½	2	2½	4	2	2½	4	2	2½	4½	2
3½	5¼	3	4	6	3	4	6	3	4½	6¾	3
5¼	7	4	6	8	4	6	8	4	6¾	9	4
7	8¾	5	8	10	5	8	10	5	9	11¼	5
8¾	10½	6	10	12	6	10	12	6	11¼	13½	6
10½	12¼	7	12	14	7	12	14	7	13½	15¾	7
12¼	14	8	14	16	8	14	16	8	15¾	18	8
14	15¾	9	16	18	9	16	18	9	18	20¼	9
15¾	17½	10	18	20	10	18	20	10	20¼	22½	10
2½-inch Nails						2¾-inch Nails					
2½	4½	2	2½	5	2	2½	5	2	2½	5½	2
4½	6¾	3	5	7½	3	5	7½	3	5½	8¼	3
6¾	9	4	7½	10	4	7½	10	4	8¼	11	4
9	11¼	5	10	12½	5	10	12½	5	11	13¾	5
11¼	13½	6	12½	15	6	12½	15	6	13¾	16½	6
13½	15¾	7	15	17½	7	15	17½	7	16½	19¼	7
15¾	18	8	17½	20	8	17½	20	8	19¼	22	8
18	20¼	9	20	22½	9	20	22½	9	22	24¾	9
20¼	22½	10	22½	25	10	22½	25	10	24¾	27½	10
3-inch Nails						3-inch Nails					
2½	5½	2	2½	6	2	16½	19¼	7	18	21	7
5½	8¼	3	6	9	3	19¼	22	8	21	24	8
8¼	11	4	9	12	4	22	24¾	9	24	27	9
11	13¾	5	12	15	5	24¾	27½	10	27	30	10
13¾	16½	6	15	18	6						

through which the other end is pulled, the lock being then bent by pressure so as to secure the end of the wire within it. Strapping must always be placed where it will lie in close contact with the box along its entire length. Such parts as fully cleated end panels must be provided with a batten to support a lengthwise strap. Lack of such support may result in snagging of the strapping, which may loosen or break it. On wooden panels more than 12″ wide, strapping or wire should be stapled to the boards at intervals of not more than 8″ and with at least one staple to every board. Shrinkage of wood due to drying will always loosen strapping and it is therefore important that strapping should be fixed immediately before shipment so that any moisture changes during storage will not affect the efficiency of the strapping.

Nailed strapping is sometimes used to reinforce the nailing of sides, top, and bottom to the ends of boxes. The strapping is tensioned by hand and the nails driven obliquely in order to pull the strapping tighter as they are driven home. Such strapping is less effective than nailless strapping, but the breaking of a strap does not destroy the whole value of the reinforcement. Nailed strapping helps to hold a split board in place.

Adhesives

The largest use of adhesives in fabricating containers is in connection with fibreboard containers and multi-wall paper bags. Vegetable paste adhesives are largely used for pasting the longitudinal joints in such bags, except in the case of water-resistant materials, which must be bonded with an equally water-resistant glue (11). Similar remarks apply to tops or bottoms of such bags as are closed by adhesives.

Fibreboard containers are supplied by the manufacturer folded flat and only the joint between one side and one end, known as the manufacturer's joint, is completed. This is commonly glued and stapled, but may also be reinforced by a strip of fabric coated with adhesive. Small containers may have no lap-over at the joint, a strip of adhesive fabric or paper making a sufficient joint for light loads. The bottom of the container, when set up by the shipper, should be glued and stapled. A cheap and convenient adhesive for this purpose is sodium silicate. This develops a quick tack strength and hardens fairly rapidly, and is not readily resoftened by water, so that it is somewhat more water-resistant than the fibreboard itself. When the container is filled, the top flaps are closed, and in the case of heavier loads it is well to apply sodium silicate to the inner flaps before folding the outer flaps in place. The longitudinal joint between the outer flaps should then in all cases be covered with a strip of adhesive paper tape (or fabric tape for heavier boxes), such tape being continued over the ends of the box. The gap between the flaps and the ends should then be closed with another strip of tape which is carried back a short distance along the top to side edge, the corners being neatly mitred and folded. The box should be turned over and the bottom similarly taped.

Sodium silicate is also useful in building up interior pads and blocking for all kinds of containers by sticking sheets of corrugated fibreboard together.

Rope, Cord, String

Cord and string are frequently used for tying parcels of small size and are useful in making up independent packages of loose parts and accessories, to be packed with a principal item in one shipping container. For the shipping container itself, however, rope, cord, and string suffer too great a variation of length with moisture and are too weak, unless excessively thick in proportion to the container, to be compared in value with steel strapping. As the latter is cheap, easily used, neat, and a great protection against pilferage, its use is recommended, except as mentioned above for certain internal packing purposes. In the case of single parcels of size and weight acceptable for delivery by parcel post, cord or string are frequently used, and give satisfactory service.

PACKING (INTERIOR)

Padding Materials

A wide variety of materials is available for padding —sawdust, wood wool (excelsior), straw, creped paper, and cotton wadding. Padding material should be sufficiently soft to conform to the shape of the article being packed, yet should be sufficiently resilient to cushion the contents against the effects of shock. It must have power of recovery so that, after such shock-induced movement, it may return the load to its normal position and still give it support.

Such materials as straw and excelsior must be rammed in tightly enough not to shake down in transit and leave the contents of the box loose, but not so tightly as to destroy their cushioning effect. The function of padding is, however, very largely to spread local shocks evenly over a wide area. A fragile wine glass, for example, which would break at a tap on the rim, would sustain a much heavier blow if well-placed padding distributed the impact over the whole area of the glass. It is also important, therefore, to distribute padding evenly, so that all parts of the objects packed are equally supported.

Blocks, Braces, and Slings

It is always desirable for a shipping container to be regular in shape, for convenience and efficiency in handling and stowing. Many articles to be packed, such as machinery, will not even approach such regular form. An article loose in a container acts like a battering ram; it may smash its own or even neighbouring containers, and can easily do itself considerable damage in the process, even though not particularly fragile. A system of blocks, braces, and slings in the container will serve to hold the contents safely in place. The design of blocks and braces must suit the requirements of the particular article being packed, and no general instructions can be given. Elastic slings are useful for large, very fragile articles of great value, such as neon signs, large rectifier tubes, and galvanometers with delicate suspensions. A rigid case is made large enough to allow considerable free movement of the article. The article is then suspended inside the case by elastic slings, so that no matter on which face the case rests, or from what direction a blow may fall, the result is only to set up free oscillations of considerable magnitude, and delicate parts of the article are not subjected to any shock.

Moisture Barriers

Any article or material that could be damaged during shipment by moisture in the atmosphere, whether in the form of vapour or rain, must be protected by being enclosed in a continuous layer of some material that is resistant to the passage of water and water vapour. Bright corrodible metal parts should be greased and, if necessary, desiccating agents such as silica-gel, enclosed in a wire mesh box, can be placed inside the moisture barrier to remove moisture present when it is sealed. When moisture barriers are used, particular care must be taken that nail points do not protrude, as they may tear or puncture the lining. Large boxes should be provided with louvred ventilation holes to minimize the risk of condensation due to temperature changes. Materials commonly used as moisture barriers are creped kraft paper with an interlayer of asphalt, waxed kraft paper, and various plastic sheetings such as cellophane or polyethylene.

CONTAINER HAZARDS AND HAZARD TESTS

Stacking

Since containers, especially small containers, will be stacked in warehouses, freight cars, trucks, and ship holds, it is necessary to know the strength required to give satisfactory service under these conditions. To measure the ability of a container to support stacking loads, it is placed, empty, between the platens of a compression testing machine and the load recorded is plotted against the corresponding deformation produced in the container. From the resulting diagram, the maximum load that can be supported by the container without its being permanently weakened, or deformed to an extent that will endanger the contents, can be assessed. In some cases, such as when canned foods are packed in fibreboard containers, the cans themselves are well able to support the stacking load, the container in this case serving chiefly to keep the consignment together and protect it from damp, dirt, and spoilage of labels.

Distortion

A box or crate must be able to resist distortion such as may be caused by pulling and pushing on the top to turn the crate on the floor, or to cant it on to a hand truck, or by the motion of a ship pitching and rolling in a heavy sea. The ability to resist distortion is assessed by the compression load being applied to opposite edges, or corners, instead of opposite faces (Pl. 102). Alternatively, the top and bottom of the crate or box may be confined in frames and a torque applied. The moment of the torque is plotted against the displacement of the top relative to the bottom. As before, the extent of distortion must not be great enough to cause permanent damage to the container or harm to the contents.

Rough Shunting

This is a hazard peculiar to railroad freight, and arises from a locomotive or train approaching stand-

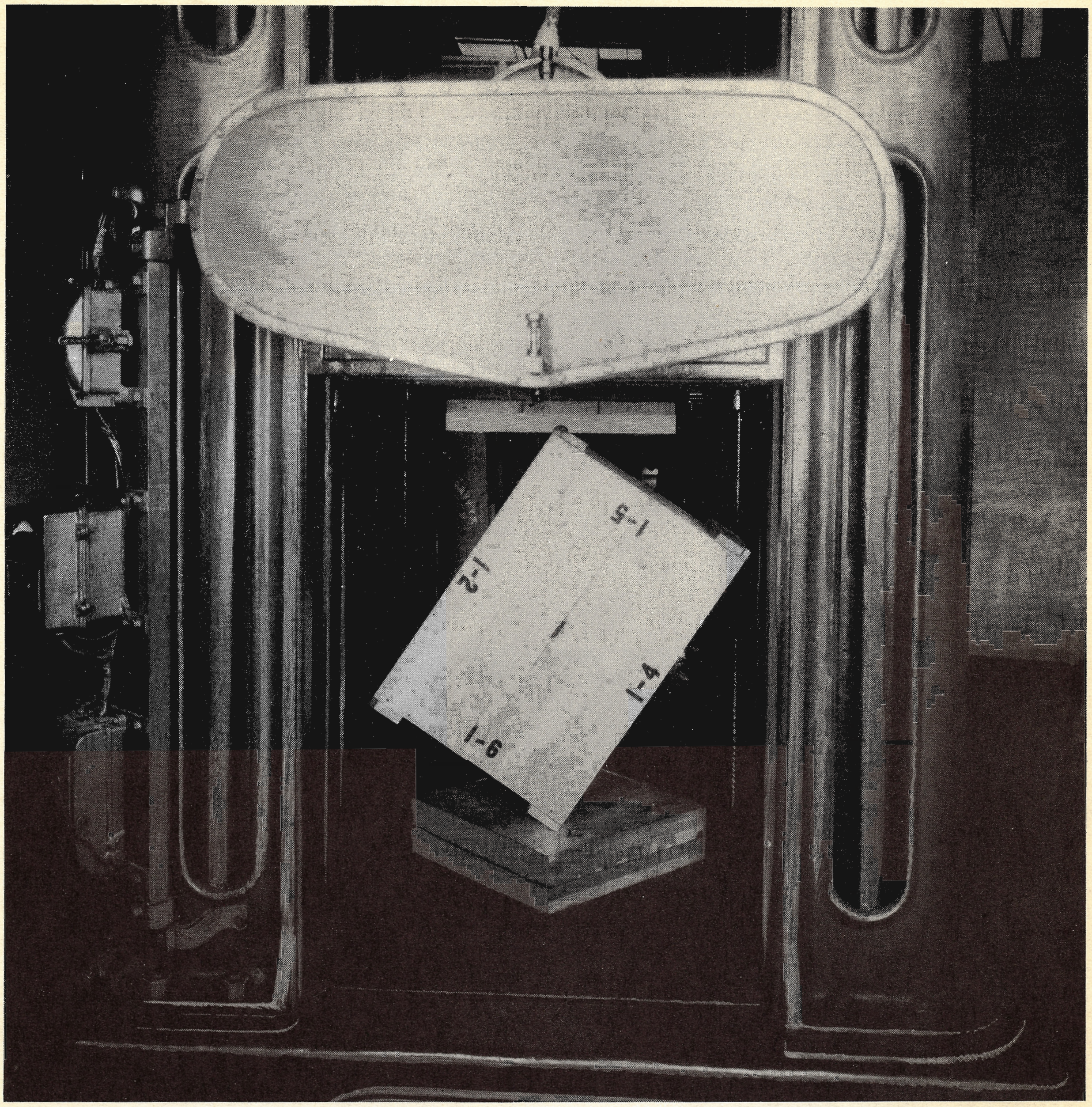


PLATE 102.—Corner-wise Compression Test.

ing freight cars at too high a speed or, in assembling a train, from a free-running car striking those already assembled without first having been sufficiently checked by the brakeman. The behaviour of a container under this kind of shock may best be assessed by means of the inclined impact (Conbur) machine. This consists of a short length of track (10 or 12 feet suffices for most purposes), inclined at an angle of 10°, and having at the bottom a massive rigid wall at right angles to the track. A free-running dolly runs on the track, and on this is placed the container with its leading edge or face flush with the leading edge of the dolly. The dolly is released from a known distance up the track, striking the wall with a known speed. The extent of damage to the container, combined with the known speed of impact, provides a basis for the comparison of different styles of containers and methods of internal packing.

Rough Handling

General rough handling by porters and stevedores is not so easy to evaluate as the foregoing case of rough shunting, where the direction of the blow is fairly accurately known. A container that is dropped may fall on any face, edge, or corner. To simulate this hazard, a large drum, either seven or fourteen feet in diameter, is used; this drum has a hexagonal cross-section internally, and guides are placed on the faces in such a way that, when the drum is rotated, the container being tested receives in falling from one face to another blows on its various corners, edges, and faces. Plate 103 shows the fourteen-foot hazard machine. The length of time a container stands up to this treatment indicates its relative serviceability, and the parts that break first disclose the more important structural weaknesses and suggest to the observer ways of improving the container. Comparison with actual shipping conditions is obtained by experience in service with containers similar to those tested.

Strength of Fibreboard

There are two machines in general use for estimating the strength of fibreboard, both solid and corrugated. The most common is the Mullen or Cady burst strength machine. In this machine, the board is clamped by a ring over a circular aperture, beneath which is a rubber diaphragm closing a hydraulic cylinder filled with glycerine. A pressure gauge measures the pressure in the cylinder. The ram is advanced in the hydraulic cylinder at a standard rate and the rubber diaphragm is pressed upwards until the board bursts. The gauge indicates the maximum pressure reached.

The other type is the Beach puncture testing machine, which simulates the effect of a hard box corner falling on the carton. It is a pendulum-type impact machine, in which the blow is delivered by a steel point in the form of the corner of a cube. The test board is supported between steel plates so as to cover a triangular orifice, through the centre of which the point passes. The energy absorbed from

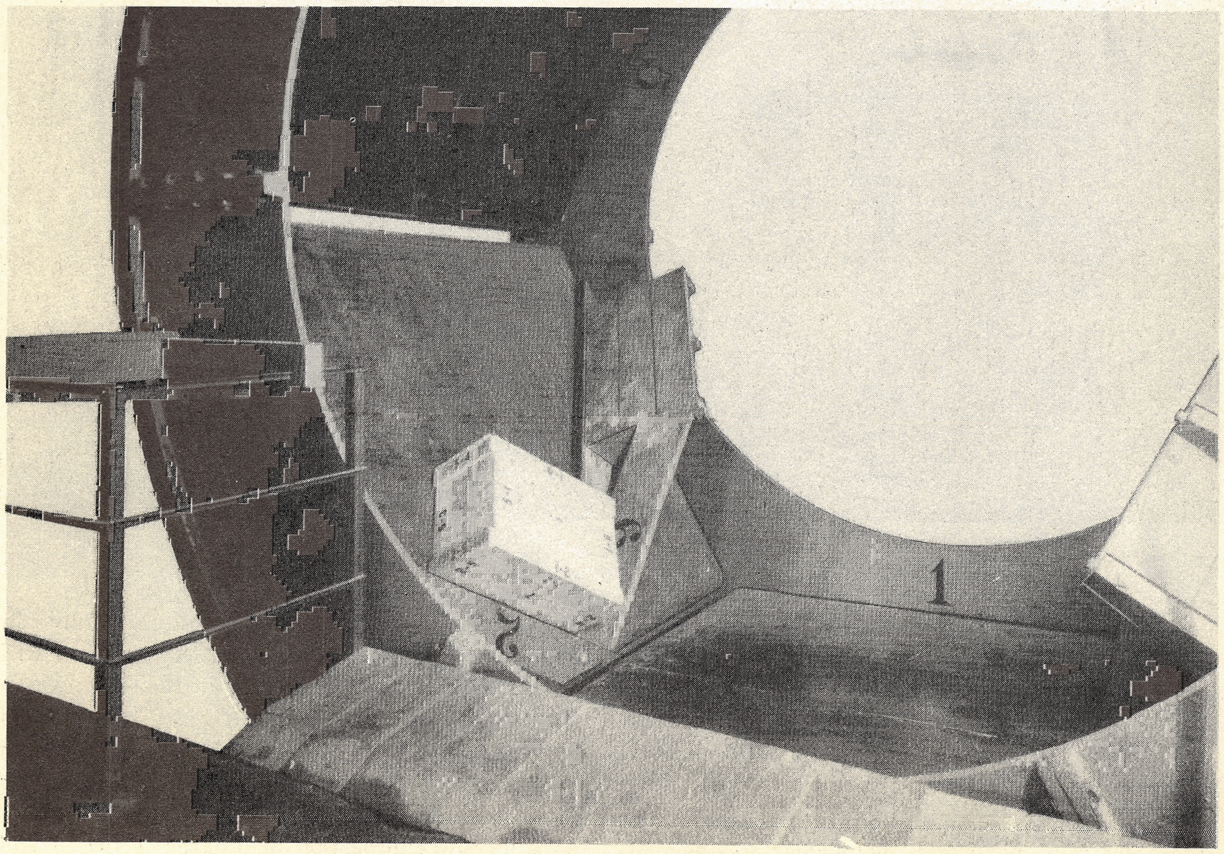


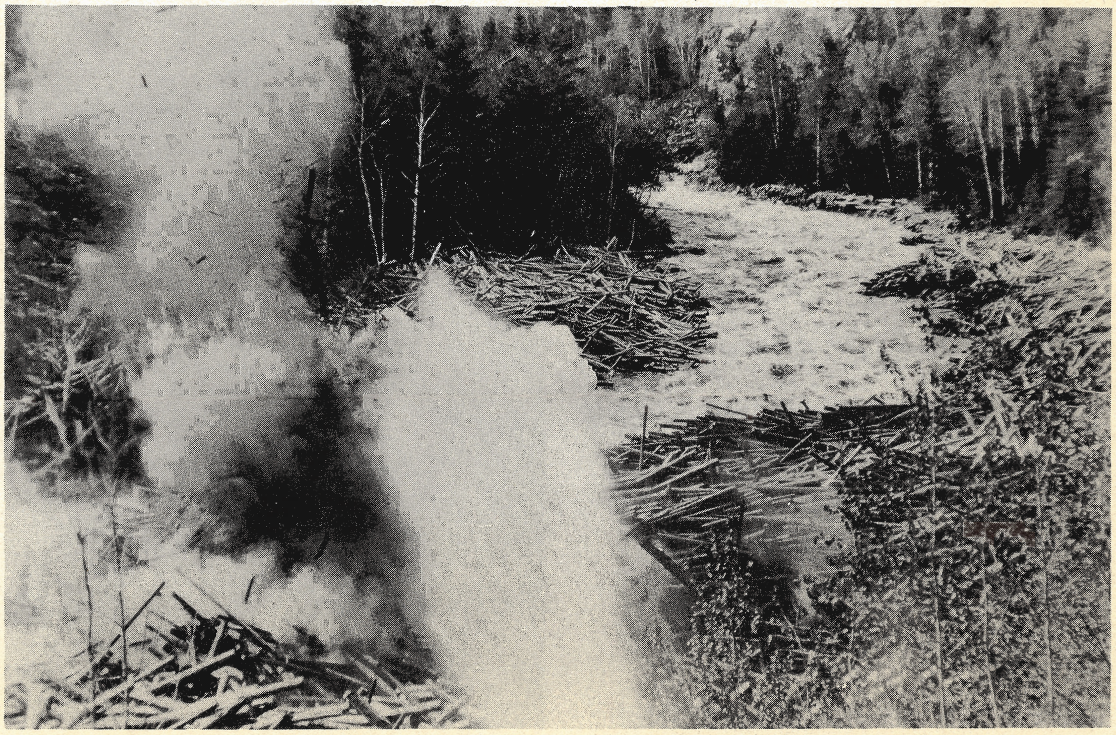
PLATE 103.—Fourteen-foot Hazard Machine.

the pendulum by the blow is indicated on a scale by a pointer pushed to the limit of the overswing of the pendulum.

GENERAL

Pilferage, Marking, Advertising

It is unfortunate, but none the less true, that in most parts of the world pilferage ranks high in the causes of short or damaged shipments at destination. It is not economically practicable to make a shipment thief-proof, but certain simple precautions will render the attentions of thieves less likely. For the most part, these precautions are closely related to good packing practice. The package that invites pilferage is one that has burst accidentally in such a manner as to expose the contents. It is the work of a moment to widen the break and pocket some of the articles in the box. The pilferer will not waste time on a box that is hard to open, or that will leave positive and obvious evidence of having been forced, nor is he much concerned with things that cannot be carried away unobtrusively. Boxes and cartons that are strapped, especially when each board is stapled to the strapping, are less easy to open surreptitiously than if left unstrapped. Containers that are small enough to carry away, if all for the same destination, should be securely bundled or palleted. This is good practice in any case, as it reduces handling costs and risks of damage from rough handling. Accurate address and shipping marks in letters of the size specified by the railroad or shipping company, preferably stencilled on each container, play a part in reducing risk of pilferage (13). Such containers are less likely to be delayed in goods yards or docks, and so are exposed to risk for a shorter period. They are not as vulnerable as illegibly or inaccurately marked containers that may be set aside for identification out of the general traffic of the depot. The practice of putting advertising matter on the outside of containers should be discouraged, as it is of doubtful advertising value, and serves to invite the attention of the pilferer, especially to small goods much in demand. A freight handler may not be tempted to break open a secure container when ignorant of its contents, but if his attention is drawn by advertising matter to an article he wants, the container may be "accidentally" broken to provide an opportunity to pilfer some of the contents.



Blasting a Log Jam.

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2	C.P.C. 12	Crates, Wooden, Nailed.
3	C.P.C. 1	Wood, General.
4	C.P.C. 14	Boxes, Wooden, Cleated, Plywood.
5	C.P.C. 13	Boxes, Wooden, Wirebound.
6	C.P.C. 18	Drums, Plywood.
7	C.P.C. 2	Nails and Spikes.
8	C.P.C. 3	Screws, Wood.
9	C.P.C. 4	Strapping, Round, Steel, Coated.
10	C.P.C. 5	Strapping, Flat, Steel.
11	C.P.C. 116	Barriers, Water-Resistant (Adhesives for).
12	C.P.C. 100	Methods of Preservation and Interior Packaging.
	C.P.C. 102	Corrosion Prevention—Methods of Cleaning and Drying.
	C.P.C. 103	Corrosion Prevention, Materials and Application.
	C.P.C. 105	Wrapping, Greaseproof.
	C.P.C. 107	Compound, Coating and Sealing.
	C.P.C. 111	Barriers, Moisture-Vapour Resistant.
	C.P.C. 112	Desiccants, Activated.
	C.P.C. 115	Barriers, Water-Resistant (Materials for).
	C.P.C. 117	Barriers, Water-Resistant, Methods of Application.
	C.P.C. 118	Tape, Pressure Sensitive, Water-Resistant.
13	C.P.C. 251	General Marking and Identification for Export.
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Lignum Vitae Tobacco Jar*

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*This fine specimen of modern craftsmanship was made by a member of the Canadian Expeditionary Force in World War I.

†From 16th century engraving by Hieronymous Wierix. It is interesting to note how little the basic tools of the woodworkers' craft have altered in the intervening centuries.

Title page to Life of Christ†

TIMBER FASTENERS

by J. M. RUDNICKI

TIMBER fasteners are of many different types, sizes, and shapes, each adapted to one or several of the variety of uses for which lumber is employed. Size, shape, stresses involved, and many other factors have to be evaluated when a particular type and size of fastener is chosen for a given use. Suitable and dependable fastenings are required for many different types of assembly, varying in size and importance from boxes to structural timbers. The elements of permanency, strength, and durability do not always apply equally and choice of a particular type or size of fastener should be related to the requirements of each particular application.

Herein only the more important of the pertinent data will be given for those types of timber fastenings in general use, as well as for some types suitable for special uses.

NAILS

The production of common wire nails in their present form started on a commercial scale about 1850. Early in the 19th century, nails were forged by hand and had no standard design, the shape of the nail being left to the smith's judgment.

The "penny" (d) system of designating nails undoubtedly originated in England, and many explanations have been given as to the origin of this practice.* While present usage recognizes the 'penny' size as indicating a definite length of nail or spike, the designation is gradually being replaced by the practice of designating nails according to their diameter and length in inches. Table 37 shows 'penny' sizes for nails and spikes, and their corresponding length in inches.

PENNY SIZES OF NAILS AND SPIKES, WITH CORRESPONDING LENGTHS IN INCHES TABLE 37

Size	2d	3d fine	3d	4d	5d	6d	7d	8d	9d	10d	12d	16d	20d	30d	40d	50d	60d
Length in Inches	1	1⅛	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6

*According to the Concise Oxford Dictionary, 'fivepenny', 'tenpenny', etc. nail sizes indicated the number of pence originally charged for one hundred nails of that size.

Nail Points and Nail Heads

The ease with which nails of various types can now be made with modern machinery has resulted in a large variety being manufactured, and of these certain types of points (Fig. 50) and heads (Fig. 51) have become popular for various uses. The most common nail points are:

1. Diamond point—adopted for general commercial use.
2. Chisel point (driven into the wood in such a way as to cut across the fibre)—generally used on large nails to facilitate penetration without splitting the wood.
3. Needle point—facilitates the penetration of the nail into the wood. It can be used on any wood except the harder species. Needle-pointed nails are likely to cause splitting when used with the harder species.
4. Blunt point—used with the harder wood species. It is frequently specified for nailing hardwood floors. It has a tendency to crush the fibres rather than to wedge them apart, which latter causes splitting.

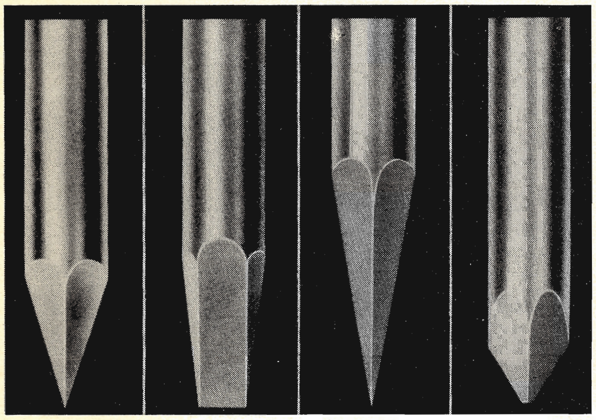


FIGURE 50.—Types of Nail Points.

The most common nail heads are:

1. Flat head—adapted for general use in carpentry and joinery.
2. Finishing head—adapted for those types known as finishing nails. The head penetrates into the wood without appreciably crushing the surface fibres and can be readily concealed.
3. Large flat head—the type of nail head used mostly to nail thin sheeting to a frame. Roofing nails present an example of this type.

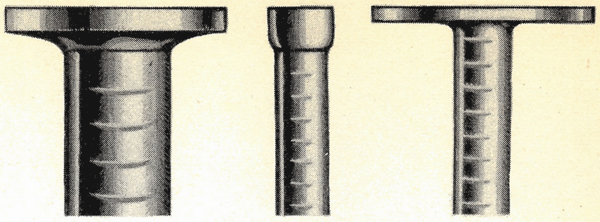


FIGURE 51.—Types of Nail Heads.

Nail Shank

Considerable effort has been expended on the study of nail shanks, in order to improve withdrawal resistance. Research work has been based on the idea of increasing the withdrawal resistance of the nail by various means. One method was to increase the contact area between the nail shank and the wood without increasing the nail's weight. The cross-section of the nail shank was changed from round to rectangular, triangular, etc., or was longitudinally grooved. Another method was to treat the nail surface in contact with the wood by employing various types of nail coating, or by subjecting the nail shank to special treatments (4, 14).

Increasing the shank area in contact with the wood, without adding to the weight of the nail, was found to increase the resistance to withdrawal.

Some cement coatings increase the withdrawal resistance of nails temporarily. A cement coating of good quality will increase the resistance of nails to withdrawal immediately after driving from 85 to 100 per cent, as compared with uncoated nails, and even more when the coated nails are used with the lighter woods, such as the softer pines. Coated nails show little advantage when used with the heavier woods, such as hard maple, birch, or oak. The increase in resistance to withdrawal of cement-coated nails, when they are used with the softer woods, partly disappears after a time. In a month or so, only about one-half of the initial increase remains (3, 14).

A zinc coating is occasionally given to nails, primarily to reduce or prevent their corrosion. If the coating is evenly applied, it may increase the resistance to withdrawal, but extreme irregularities of the coating may even reduce such resistance (14).

Nail Withdrawal Resistance

Nail withdrawal resistance may be defined as the ability of wood to resist the extraction of a nail; it

is equal to the minimum tensile force in pounds, applied axially to the nail, necessary to effect its extraction. It is closely related to the area of the shank of the nail in contact with the wood, and to the physical properties of the species of wood used, provided that no splitting occurs when the nail is driven into the wood.

Tests (14) have indicated that the load required to withdraw common wire nails from the side grain of seasoned wood is obtained by the following formula:

$$P = 6900G^{2\frac{1}{2}}D.$$

In this formula, P is the load per inch of penetration; G the specific gravity (based on weight and volume oven-dry); and D the diameter in inches of the nail.

The load P, as determined by this equation, is not as accurate for some species as for others, because of the variability of certain physical characteristics, such as a tendency to split.

In designing nailed construction, it is usual to apply a factor of safety to the theoretical withdrawal load P in the preceding formula. This factor is usually six, and the formula for safe load becomes:

$$P_1 = 1150G^{2\frac{1}{2}}D.$$

Investigation showed that if the moisture content of the wood surrounding the nail shank decreased, the withdrawal resistance of the nail dropped also, and that some woods lose a larger part of their nail-holding power than others. If the wood was moist when the nails were driven, rusting of the nail frequently occurred and the withdrawal resistance was increased somewhat above the normal expected as a result of the seasoning.

Slant-driving of Nails

The numerous tests made showed that nails driven in a toed-in or toed-out pattern and nails driven slanting in the same direction have lower withdrawal resistance than the same nails driven vertically. However, in the case of nails driven into green wood which is seasoned to the air-dry condition before the nails are pulled out, the toed-in nails have a higher withdrawal resistance than the nails driven into the wood in a direction perpendicular to the surface (8).

Lateral Resistance

Lateral load indicates a load (measured in pounds) applied at right-angles to the axis of the nail; and lateral resistance is the ability of the nail to support an imposed lateral load.

The United States Forest Products Laboratory recommends the following formula for expressing the safe lateral load for wire nails driven into air-dry wood:

$$P = K \cdot D^{3/2}$$

in which:

P = safe lateral load in pounds per nail.

K = constant determined by tests. Values are shown in the table below.

D = diameter of nail in inches.

Maximum loads for coniferous woods will be about six times and for hardwoods about eleven times the recommended safe loads (14).

VALUES OF CONSTANT K IN FORMULA FOR SAFE LATERAL LOADS FOR WIRE NAILS DRIVEN INTO AIR-DRY WOOD

TABLE 38

SPECIES	CONSTANT
Softwoods:	
Cedar, eastern white; fir, balsam; hemlock, eastern; pine, lodgepole, ponderosa, western white, white; spruce, Engelmann, red, Sitka, white.	900
Cedar, western red, yellow; Douglas fir (mountain type); hemlock, western; larch (tamarack); pine, red.	1125
Fir, Douglas (coast type); larch, western.	1375
Hardwoods:	
Basswood; butternut; chestnut; poplar, aspen, black cottonwood, cottonwood.	900
Alder, red; ash, black; birch, white; elm, slippery, white; hackberry; maple, broadleaf, red, silver	1250
Ash, white; beech; birch, yellow; cherry, black; elm, rock; hickory, shagbark; maple, sugar; oak, red, white; walnut, black.	1700

These recommendations are based on a depth of penetration into the block receiving the point of not less than ten times the diameter of the nail for dense woods, to fourteen times the diameter for the softer woods. It is also assumed that the wood of the cleats is not greatly different in density from that of the block holding the point: *when nails are holding metal to wood*, the safe lateral resistance as determined from the given equation can be *increased by about 25 per cent*. In cases where the character of the work is such that higher loads appear safe, or when in the opinion of the designer it is felt that the factors of safety used are generally too conservative, the co-efficient preceding $D^{3/2}$ may be raised accordingly. The U.S. Forest Products Laboratory, however, does not recommend smaller factors of safety for permanent concealed joints (14).

The above formula applies to wire nails driven perpendicular to the grain. There is practically no difference whether the lateral load is applied in a direction parallel with, or transverse to the grain.

Safe lateral loads for nails driven parallel to the grain, that is, into the end of a piece, should be about 60 per cent of those for nails driven perpendicular to the grain (14).

Moisture Content of the Wood

The safe lateral loads recommended for seasoned wood should be reduced by 25 per cent when applied to nails driven into unseasoned wood which will remain wet, or which will be loaded before seasoning has taken place (14).

The limited available information and erratic behaviour under tests make it difficult to recommend safe lateral loads for nails driven into green wood and loaded during or subsequent to seasoning. Important structural joints subjected to these conditions should be inspected at intervals, and, if joints show a loss of strength as the timbers dry, they should be reinforced with additional nails: setting the old nails is not sufficient.

Common Wire Spikes

Common wire spikes are manufactured in the same manner as common wire nails. They may have a chisel, a diamond, or some other variety of point, and are usually designated by inches of length.

The safe withdrawal resistance in pounds per linear inch when driven perpendicular to the grain may be calculated by the formula:

$$P = 1150\, G^{2\frac{1}{2}} D$$

Where P = the safe withdrawal load in pounds per inch of penetration,

Where G = specific gravity of the wood (weight and volume oven-dry),

Where D = diameter of the spike in inches.

In calculating the withdrawal load, two-thirds of the length of the point should be disregarded. However, to bring Sitka spruce and white pine into closer agreement with the values obtained from actual tests, the value for P should be 10 per cent greater for Sitka spruce and 20 per cent greater for white pine than the value computed from the equation. The lateral resistance of common wire spikes may be calculated by the formula given on page 307 for common wire nails.

The foregoing recommendations assume that the spikes are driven into pieces of wood of sufficient width and length and far enough from the ends or edges to avoid splitting (14).

Wood Screws

Wood screws are usually made from brass or steel and are composed of a head, a cylindrical shank, and a threaded part, tapered to a point to facilitate the penetration of the screw into the wood. They are produced with different types of heads, and in different lengths and gauges, in order to adapt them to a variety of uses.

As in the case of nails, more satisfactory results will be obtained if care is taken to select the particular size, length, and type of screw most suitable for the intended use.

Withdrawal Resistance

Withdrawal resistance may be defined as the ability of wood to resist the extraction of a screw and is the minimum tensile force in pounds, applied axially to the screw, necessary to effect its removal. Tests made by the U.S. Bureau of Standards indicate that this relation may be expressed as follows:

$$P = 10200 G^2 D$$

Where P = ultimate load in pounds per inch of total length of screw,

Where G = specific gravity of the wood, based on oven-dry weight and volume when tested,

Where D = diameter of screw shank in inches (14).

It is presumed that the depth of penetration into the block receiving the point is not less than two-thirds the length of the screw, and that the screw is inserted into the side grain of wood seasoned to approximately 15 per cent moisture content.

If a safety factor of 6 is applied to this equation the safe load (P_1) becomes:

$$P_1 = 1700G^2D$$

The lead holes should be about 70 per cent of the root diameter of the screw in softwood and about 90 per cent in hardwood.

The equation values are applicable to the following screw lengths and gauges:

Screw lengths in inches	Gauge limits
½	1—6
¾	2—11
1	3—12
1½	5—14
2	7—16
2½	9—18
3	12—20

For lengths and gauges outside these limits, the actual values are likely to be less than the equation values, especially in the denser woods where screw failures often occur. The equation may be used for all species, but inherent characteristics may cause some species to give values 10 to 15 per cent above or below the equation values, while an occasional species may vary more than this (14).

When screws are driven parallel to the grain, that is into the end-grain of a piece, the individual results are erratic, but, where splitting can be avoided, they should develop, on the average, about 75 per cent of the load computed for side-grain.

A lubricant such as soap may be used where necessary for easy insertion with but little loss in holding power. Other conditions remaining constant, a screw can be unscrewed from wood and replaced in the original hole with no loss of withdrawal resistance value (1).

Lateral Resistance

The lateral loads which can be supported by screws are proportional to the square of the screw diameter in inches when air-dry lumber is used, provided that the cleats used are of the approximate density of the main member, and that the screw penetrates into the main member to a depth of about seven times its shank diameter.

$$P = K \times D^2$$

Where P = ultimate lateral load supported by a wood screw in pounds. (The expected slip between members will be between 0.007 and 0.010 of an inch, under the safe lateral load.)

Where D = diameter of the screw shank in inches.

Where K = constant for different species as shown in table below.

CONSTANT (K) VALUE FOR WOOD SCREWS IN WOOD AT 15 PER CENT MOISTURE CONTENT EXPRESSED IN POUNDS PER SCREW

TABLE 39

GROUP	SPECIES	CONSTANT
	Softwood (conifers)	
1	Cedar, eastern white; fir, balsam; hemlock, eastern; pine, lodgepole, ponderosa, western white, white; spruce, Engelmann, red, Sitka, white	12600
2	Cedar, western red, yellow; fir, Douglas (mountain type); hemlock, western; pine, red; larch (tamarack)	16200
3	Fir, Douglas (coast type); larch, western	19800
	Hardwood (broad-leaved species)	
1	Poplar, aspen, large-tooth, cottonwood, black cottonwood; basswood; butternut; chestnut	12600
2	Alder, red; ash, black; birch, paper; elm, white, slippery; hackberry; maple, broadleaf, red, silver	17400
3	Ash, white; beech; birch, yellow; cherry, black; elm, rock; hickory, shagbark; maple, sugar; oak, red, white; walnut, black	24000

If the length of screw in the main member is less than seven times the diameter of the screw, the ultimate load will diminish approximately in proportion to the lesser depth of penetration of the screw into the main member. For hardwoods, such as oak, the part of the lead hole receiving the shank should be of the same diameter as the shank, and that receiving the threaded portion should be the size of the root diameter of the thread. For conifers, such as Douglas fir, the part of the hole receiving the shank should be about seven-eighths the diameter of the shank and that receiving the threaded portion about seven-eighths of the root diameter of the thread. A *safety factor of 6* is adopted for most types of construction*. However, it is felt that the designer should be free to adopt for a given construction any safety factor which should prove satisfactory when all the factors involved are taken into consideration (14).

Bolts

Bolts are generally made of steel, and consist of a head and a cylindrical shank, the end of which is threaded to receive a nut which serves to draw the bolt tight and hold it in place.

Bolts are used to fasten two or more wooden members and are commonly employed in timber structures. They are adapted for use alone, with metal washers or plates, or with timber connectors.

When using bolts, it is important to take into consideration that the stress in the wood under the bolt is not uniform, but is concentrated at the edges of the timbers somewhat as shown by the shaded areas in Figure 52. Consequently, the percentage of the basic stress, Table 41, used to compute the safe long-time load of a bolted timber joint diminishes with the increase of the ratio of the length of bolt in a timber to the bolt diameter (Table 42).

In a bolted joint, the slip, up to a certain load, is proportional to the load which may be accepted as the proportional limit load; however, this is not correct in the true sense of the term "proportional limit load", since the joint will retain a slight set if the load is removed.

Safe long-time loads, based on proportional limit loads, may be computed by using the data recommended by the United States Forest Products Laboratory and shown in Tables 41, and 42.

*If the screws are holding metal to wood, a factor of 4½ is generally used.

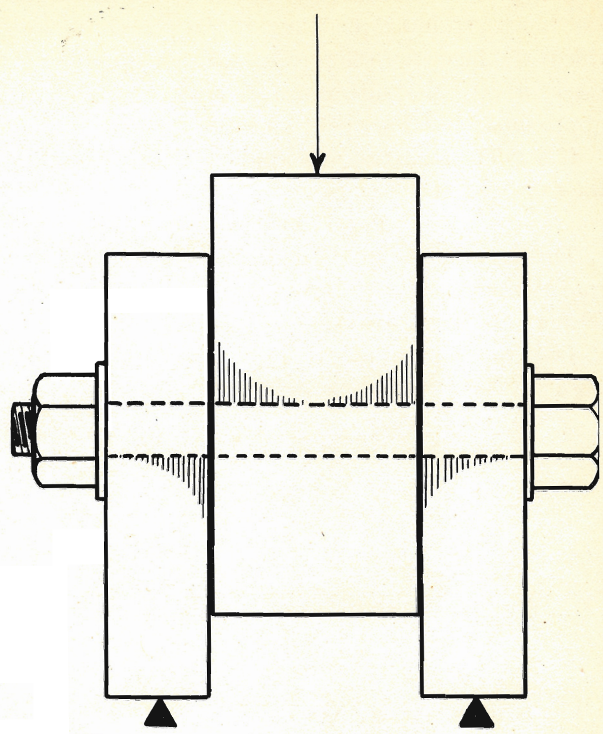


FIGURE 52.—Stresses in Bolted Joint.

To calculate the safe long-time load applied *parallel with the grain* on a timber joint through metal plates at both ends of the bolts, proceed as follows:

$$S \times r \times A \times N = P$$

S= basic stress in compression parallel with the grain from Table 40, for the kind of wood used and for the service condition which is encountered.

r= stress percentage from Table 41, for given ratio of bolt length in the main member to its diameter (L/D).

A= the projected area of the bolt, in other words, bolt length in the main member times bolt diameter.

N= number of bolts.

P= safe load applied to timber joint parallel with the grain, through metal plates at both ends of the bolts.

If the load is applied through wood splices, each of which is half the thickness of the centre timber, the safe load P^1 is obtained by multiplying safe load P as above by 0.8.

BASIC STRESSES FOR CALCULATING SAFE LOADS FOR BOLTED JOINTS*

TABLE 40

GROUP	SPECIES	BASIC STRESS, LBS. PER SQUARE INCH. Parallel with the grain	Perpendicular to the grain
Softwoods (conifers)			
1	Cedar, eastern white; fir, balsam; hemlock, eastern; pine, lodgepole, ponderosa, western white, white; spruce, Engelmann, red, Sitka, white	800	150
2	Cedar, western red, yellow; fir, Douglas (mountain type); hemlock, western; pine, red	1000	200
3	Fir, Douglas (coast type); larch, western, tamarack	1300	275
Hardwoods (broadleaved species)			
1	Ash, black; basswood; birch, white; butternut; chestnut; poplar, aspen, black cottonwood, cottonwood, large-tooth aspen	925	175
2	Alder, red; elm, slippery, white; hackberry; maple, broadleaf, red, silver	1200	250
3	Ash, white; beech; cherry, black; birch, yellow; elm, rock; hickory, shagbark; maple, sugar; oak, red, white; walnut, black	1500	400

*The stresses indicated, when used in conjunction with Tables 41 and 42, give safe bearing stresses for bolts. They apply to seasoned timbers used in a dry, inside location. For other conditions, reduce each stress as follows: when the timbers are occasionally wet, but dry quickly, use three-fourths of the stress listed; if the timbers are damp or wet most of the time, use two-thirds of stress given.

PERCENTAGE OF BASIC STRESS, PARALLEL WITH THE GRAIN* FOR CALCULATING SAFE BEARING STRESSES UNDER BOLTS

TABLE 41

LENGTH OF BOLT IN MAIN MEMBER DIVIDED BY ITS DIAMETER (L/D)	PERCENTAGE OF BASIC STRESS FOR COMMON BOLTS[1] Group 1	COMMON BOLTS[1] Group 2	COMMON BOLTS[1] Group 3	HIGH-STRENGTH BOLTS[2] Group 1	HIGH-STRENGTH BOLTS[2] Group 2	HIGH-STRENGTH BOLTS[2] Group 3
1 to 2, inc.	100	100	100	100	100	100
2.5	100	100	99.7	100	100	100
3	100	100	99.0	100	100	100
3.5	100	99.3	96.7	100	100	99.7
4	99.5	97.4	92.5	100	100	99.0
4.5	97.9	93.8	86.8	100	100	97.8
5	95.4	88.3	80.0	100	99.8	96.0
5.5	91.4	82.2	73.0	100	98.2	93.0
6	85.6	75.8	67.2	100	95.4	89.5
6.5	79.0	70.0	62.0	98.5	92.2	85.2
7	73.4	65.0	57.6	95.8	88.8	81.0
7.5	68.5	60.6	53.7	92.7	85.0	76.8
8	64.2	56.9	50.4	89.3	81.2	73.0
8.5	60.4	53.5	47.4	85.9	77.7	69.6
9	57.1	50.6	44.8	82.5	74.2	66.4
9.5	54.1	47.9	42.4	79.0	71.0	63.2
10	51.4	45.5	40.3	75.8	68.0	60.2
10.5	48.9	43.3	38.4	72.5	64.8	57.4
11	46.7	41.4	36.6	69.7	61.9	54.8
11.5	44.7	39.6	35.0	66.8	59.2	52.4
12	42.8	37.9	33.6	64.0	56.7	50.2
12.5	41.1	36.4	32.2	61.4	54.4	48.2
13	39.5	35.0	31.0	59.1	52.4	46.3

*The product of the basic stress, parallel with the grain, selected from Table 40, and the percentage for the particular L/D ratio and species group, taken from this table, is the safe working stress applicable to that ratio for joints with metal splice plates. When wood splice plates one-half the thickness of the main timber are used, 80 per cent of this product is the safe working stress.
[1]Bolts having a yield point of approximately 45,000 p.s.i.
[2]Bolts having a yield point of approximately 125,000 p.s.i.

The safe loading values computed by using the values from Tables 40, 41, and 42 are for bolts bearing parallel or perpendicular to the grain of the wood, spaced and aligned correctly. The loads for bolts acting at various angles to the grain between these limits can be obtained by the use of the Hankinson formula:

$$N = \frac{pq}{p \sin^2 \theta + q \cos^2 \theta}$$

N= safe load or stress in a direction at inclination θ with the direction of the grain.
p= safe load or stress in compression parallel to the grain.
q= safe load or stress in compression perpendicular to the grain.

The graphical solution of the Hankinson formula is given in the accompanying Scholten nomograph (12).

Timber Connectors

Timber connectors consist generally of rings or discs which, embedded partly in each of two adjacent members, transmit load from one to the other. Originating in Europe, before World War I, as a device for increasing the efficiency of bolted joints, they obtained their greatest development during World War II, when timber structures were extensively used in order to conserve steel for other purposes.

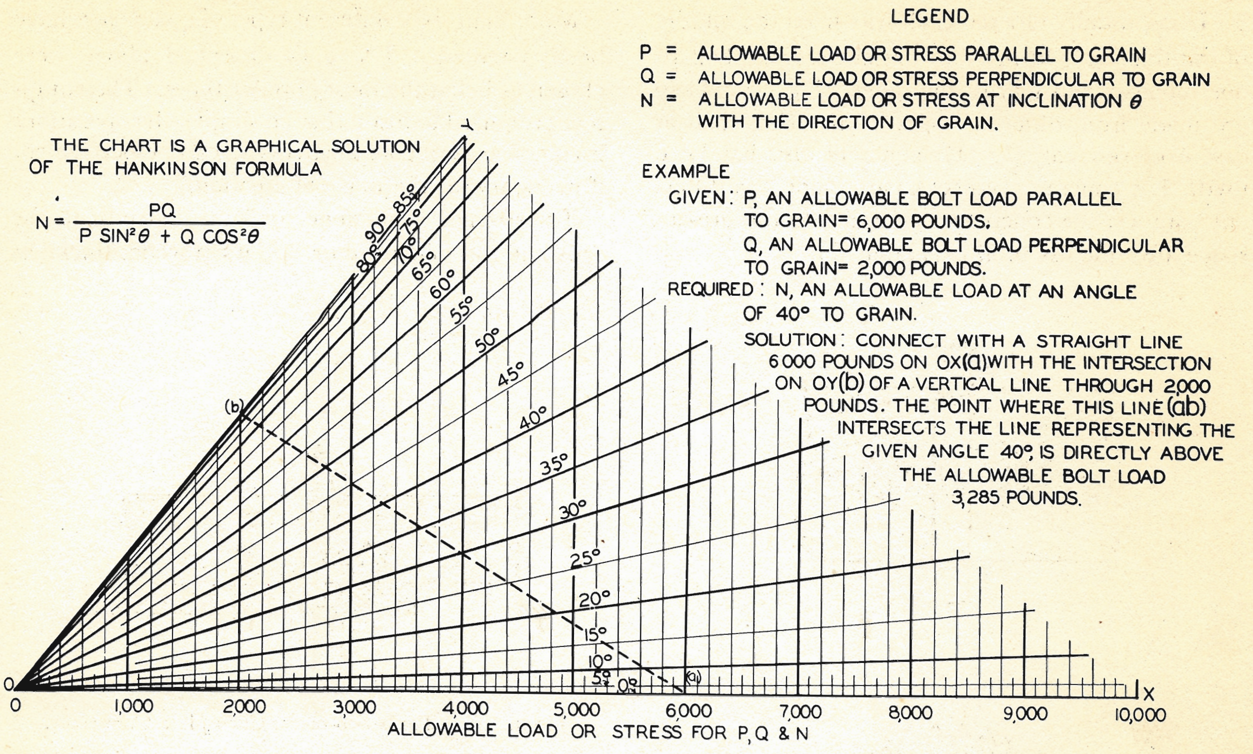
PERCENTAGES OF BASIC STRESS, PERPENDICULAR TO THE GRAIN, USED IN CALCULATING SAFE BEARING STRESSES UNDER BOLTS*

TABLE **42**

LENGTH OF BOLT IN MAIN MEMBER DIVIDED BY ITS DIAMETER (L/D)	PERCENTAGE OF BASIC STRESS FOR — COMMON BOLTS[1]: Group 1 CONIFERS & HARDWOODS	Group 2 CONIFERS	Group 2 HARDWOODS & GROUP 3 CONIFERS	Group 3 HARDWOODS	HIGH-STRENGTH BOLTS[2]: ALL GROUPS
1 to 5 inc.	100	100	100	100	100
5.5	100	100	100	99.0	100
6	100	100	100	96.3	100
6.5	100	100	99.5	92.3	100
7	100	100	97.3	86.9	100
7.5	100	99.1	93.3	81.2	100
8	100	96.1	88.1	75.0	100
8.5	98.1	91.7	82.1	69.9	99.8
9	94.6	86.3	76.7	64.6	97.7
9.5	90.0	80.9	71.9	60.0	94.2
10	85.0	76.2	67.2	55.4	90.0
10.5	80.1	71.6	62.9	51.6	85.7
11	76.1	67.6	59.3	48.4	81.5
11.5	72.1	64.1	55.6	45.4	77.4
12	68.6	61.0	52.0	42.5	73.6
12.5	65.3	58.0	49.0	40.0	70.2
13	62.2	55.3	45.9	37.5	66.9

DIAMETER OF BOLT IN INCHES	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2½	3 and over
FACTOR FOR BOLT DIAMETER	2.50	1.95	1.68	1.52	1.41	1.33	1.27	1.19	1.14	1.10	1.07	1.03	1

*The safe working stress for a given value of L/D is the product of 3 factors: (1) the basic stress, perpendicular to the grain, taken from Table 40, (2) the percentage from this table, and (3) the factor for bolt diameter, also from this table,
[1]Bolts having a yield point of approximately 45,000 pounds per square inch.
[2]Bolts having a yield point of approximately 125,000 pounds per square inch.
No reduction need be made when wood splice plates are used, except that the safe load perpendicular to the grain should never exceed the safe load parallel with the grain for any given size and quality of bolt and timber.



(REPRODUCED BY PERMISSION OF THE U.S.FOREST PRODUCTS LABORATORY)

FIGURE 53.—Scholten Nomograph. A graphical solution of the Hankinson formula.

Modern types of connectors may be classified as:

1. Plain rings which fit into pre-cut grooves in the wooden members, or toothed rings forced in under pressure. They are represented by the split-ring connector, Fig. 54, and the toothed-ring connector, Fig. 55. They are made from a split circular band of steel or a corrugated ring of steel respectively and are used for timber-to-timber connections only.

2. Plates with teeth, spikes, or corrugations which are forced into the faces of the members to be joined. They are represented by the claw-plate connector, cast from malleable iron. They fit into recesses cut in the timber, as in the case of the split-ring connector, but they have in addition short teeth which are forced further into the wood under pressure, as in the case of the toothed-ring type of connector. These connectors are used in matched pairs (male and female) for timber-to-timber connections, Figure 56, or singly for timber-to-metal connections, Fig. 57.

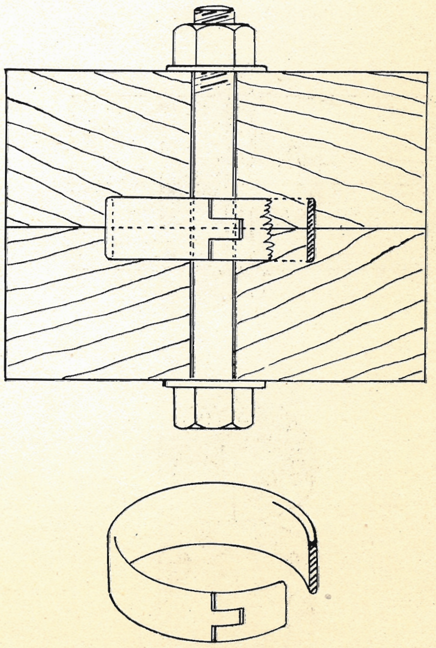


FIGURE 54.—Split-ring Connector.

3. Discs, usually tapered each way from the middle of the thickness, fitting into pre-cut recesses half in one member and half in the other, Fig. 58. They are made from different types of material, such as cast iron and oak (9, 11); concrete also has been used. The concrete connectors are made in a different manner; the concrete is poured into the pre-cut space after the assembling is done (7).

More than sixty different types of connectors have been patented. The ones described above were chosen as being the most popular types. The equipment required to instal them is simple, the operations involved are not complicated and can be performed, if necessary, at the place of erection.

The strength of a connector joint depends on the type and size of connector, species of wood, thickness

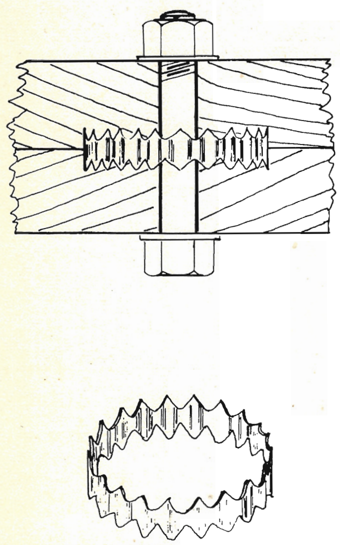


FIGURE 55.—Toothed-ring Connector.

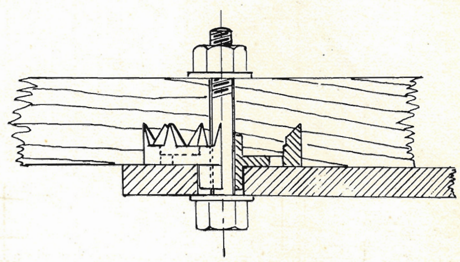


FIGURE 57.—Timber-to-metal Claw-plate Connector.

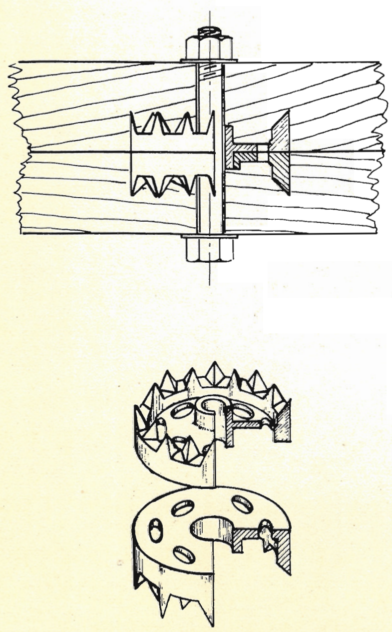


FIGURE 56.—Timber-to-timber Claw-plate Connector.

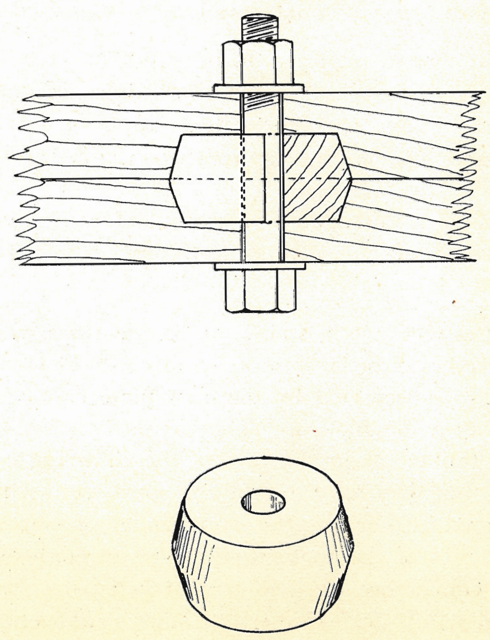


FIGURE 58.—Tapered Disc Connector.

and width of timber, the direction of application of the load with respect to the direction of the grain of the timber, seasoning of the wood, end distance and spacing of connectors, and many minor factors.

Considerable progress has been made in the theoretical stress analysis of connector joints and in correlating the results with basic data on the mechanical properties of the wood and metal. The fact remains, however, that the stress distribution is so complicated, and the assumptions involved are so often invalid, that actual tests must be relied on to provide the necessary design data (2, 6, 13).

The necessary data for use are generally supplied by the manufacturers of timber connectors. When connector joints are used in timber structures, the wood should be seasoned to a moisture content corresponding to that which it would reach in service. This is particularly desirable in the case of timber for roof trusses and other structural units used in dry locations, and where shrinkage is an important factor. However, if this condition is not obtainable in practice, maintenance should include inspection of the structural units and tightening of all bolts within three to six months after erection, and a repetition of this procedure within about a year.

Sheet Metal Anchors

Sheet metal anchors provide a new method of joining together the various components in light, framed, timber structures. Studs can be joined to the sill without the necessity of toe-nailing, and joists can be supported on the sides of timber beams, thus avoiding the waste of space that takes place when the joists are placed on top of the beams.

Depending on the use to which each type of anchor is to be subjected, the nature of the loading may vary considerably. In other words, a type B anchor, when used to fasten a stud to the sill of a frame house may be subjected to shearing forces in one of four directions caused by wind or earthquake loads, and also to direct lift, which may occasionally be caused by violent tornadoes.

Trip-L-Grip brand framing anchors are sheet metal anchors which are stamped from 18-gauge sheet steel and zinc-coated to prevent rusting. The anchors are 4⅞ inches high and are bent to form a rectangular and a triangular flange. The rectangular flange is 1⅝ inches wide and the triangular flange has a maximum width of 2¼ inches.

The A and B type anchors have, in addition, a portion of the rectangular flange bent inward or outward, respectively. The length of this bent portion is also 1⅝ inches. Nail holes have been punched in both flanges, including the bent portion of the rectangular flange and they receive the nails with a driving fit (Fig. 59). Nails of the large, flat head type are generally supplied with the framing anchors.

It is essential that a complete set of nails be used to make each connection. Care should be taken that no nail holes are left unfilled and that nails of the recommended type, length, and gauge are used.

In making connections of joists to beams, it may be sufficient to employ one "C" anchor on each end of the joist. If two anchors are used, one on each side of the joist, any eventual tendency of the joist to rotate, if unequally loaded, will be prevented.

Higher loads can be resisted by using one "C" anchor and one "B" anchor at each end of the joist as shown in Fig. 59. Still higher loads may be supported on a joist using two "C" anchors at each end. However, the two anchors should be staggered slightly in a vertical direction, to avoid the tendency of the nails to split the wood. This is the preferred type of connection if one anchor is not of sufficient capacity.

If the capacity of one anchor only is not sufficient for a given loading, and if the safe loading for the combination of the anchors to be used is not shown in Table 44, the load indicated in the table for each particular anchor forming the joint should be multiplied by a coefficient of 0.8 before being added together to obtain a total safe load for the given joint (10).

Typical Computation of Load-carrying Capacity of Two "C" Anchors Under "Y" Loading of Red Pine or White Spruce Joists

Joists of 20-foot span, spaced 16 inches on centres. Live load = 40 lb. per square foot; Dead load = 2.5 lb. per square foot.

Load on one connection composed of two "C" anchors: $42.5 \times 20 \times 1.3 \times 0.5 = 552.5$ lbs.

According to Table 44, the safe load for two "C" anchors under "Y" loading is 550 lbs.

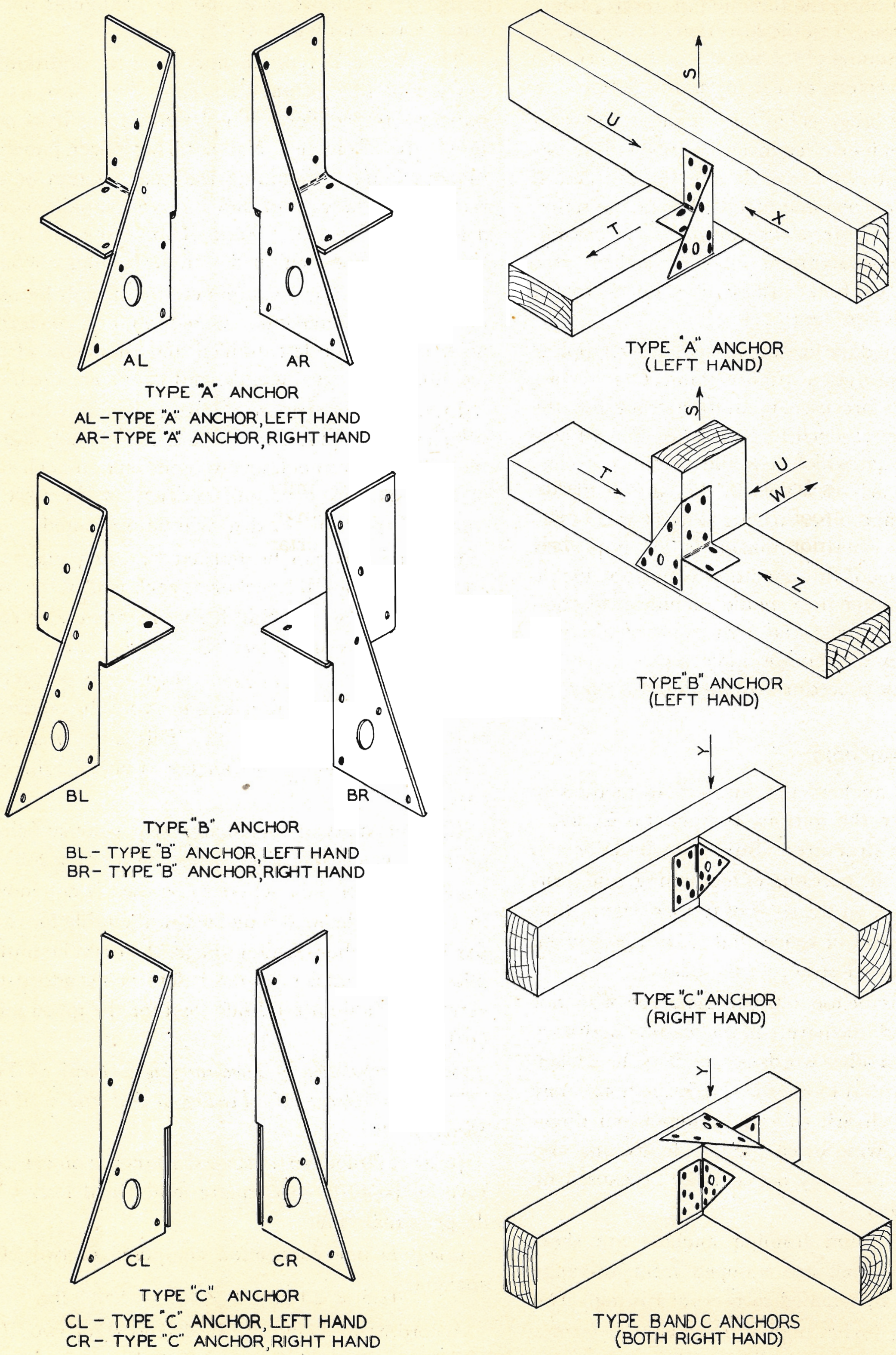


FIGURE 59.—Types and Applications of Sheet Metal Anchors.

SAFE SPANS FOR WHITE SPRUCE OR RED PINE JOISTS SUPPORTED ON TRIP-L-GRIP FRAMING ANCHORS

TABLE 43

LIVE LOAD = 40 lbs. per square foot; DEAD LOAD = 2.5 lbs. per square foot.

JOIST SPACING	*Safe Span of Joist in Feet, for a Joist Supported at each End by Anchors as follows:*		
	One "C"	One "B" and one "C"	Two "C"
16″	10.5	13	19.5
20″	8.5	10.5	15.5
24″	7	8.5	13

RECOMMENDED SAFE LOADS IN POUNDS FOR TRIP-L-GRIP ANCHORS WHEN USED WITH RED PINE OR WHITE SPRUCE*

TABLE 44

Type of Load (Fig. 59—right)	S	S	T	T	U	U	W	X	Y	Y	Y	Z
Type of Anchor (Fig. 59—left)	A	B	A	B	A	B	B	A	C	2C	B&C	B
Short-term Loading —*wind, snow, and earthquake*	400	400	650	660	220	400	300	320	600	1100	730	200
Long-term Loading —*live loads and dead loads*	200	200	325	330	110	200	150	160	300	550	365	100

*The recommended safe load is for a connection made with one anchor only—except in the cases of "Y—2C" and "Y—B&C" where two anchors are used as specified. In these cases "safe load" applies to a connection made with two "C" type anchors or with one "B" and one "C" type anchor.

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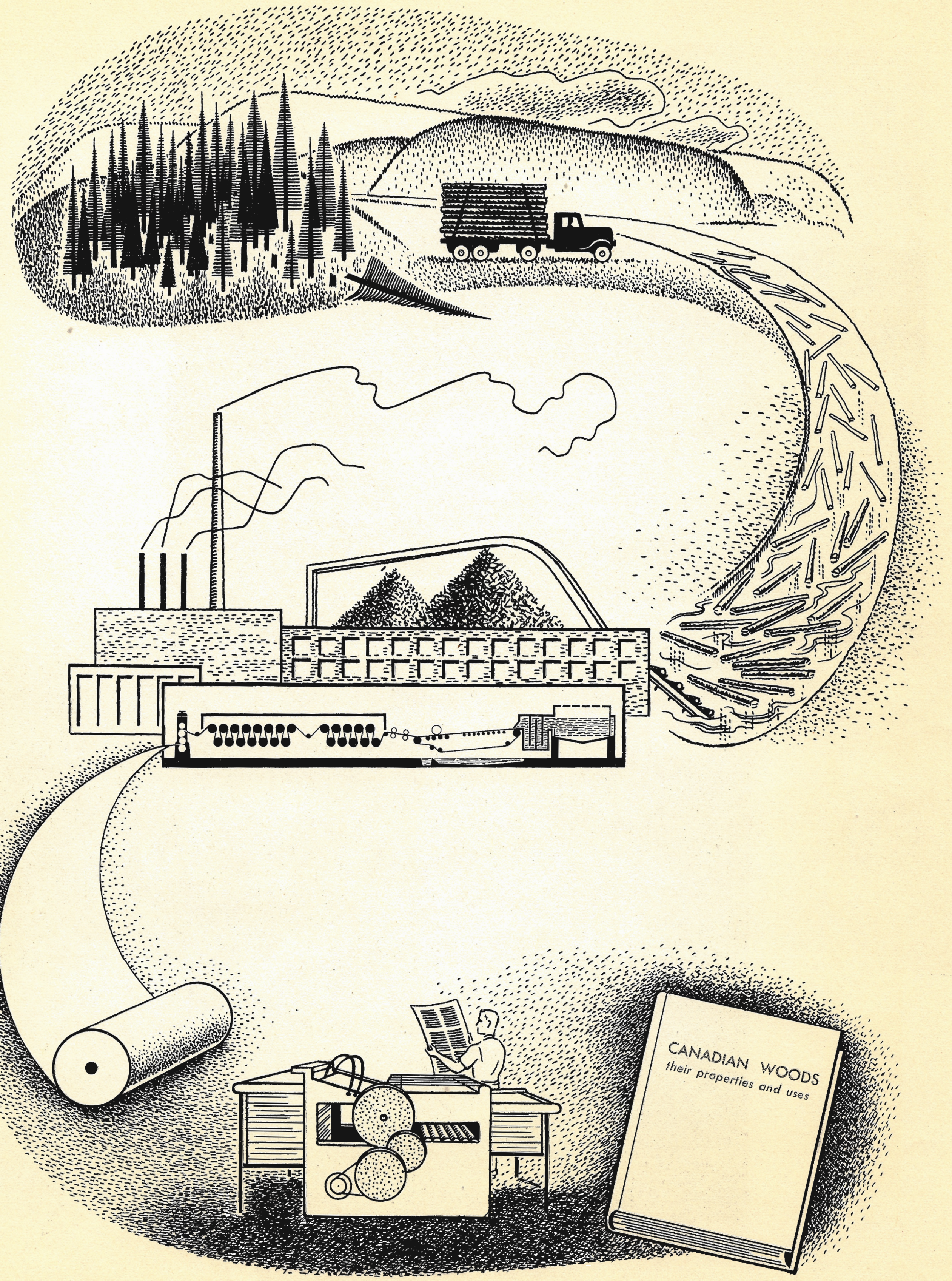
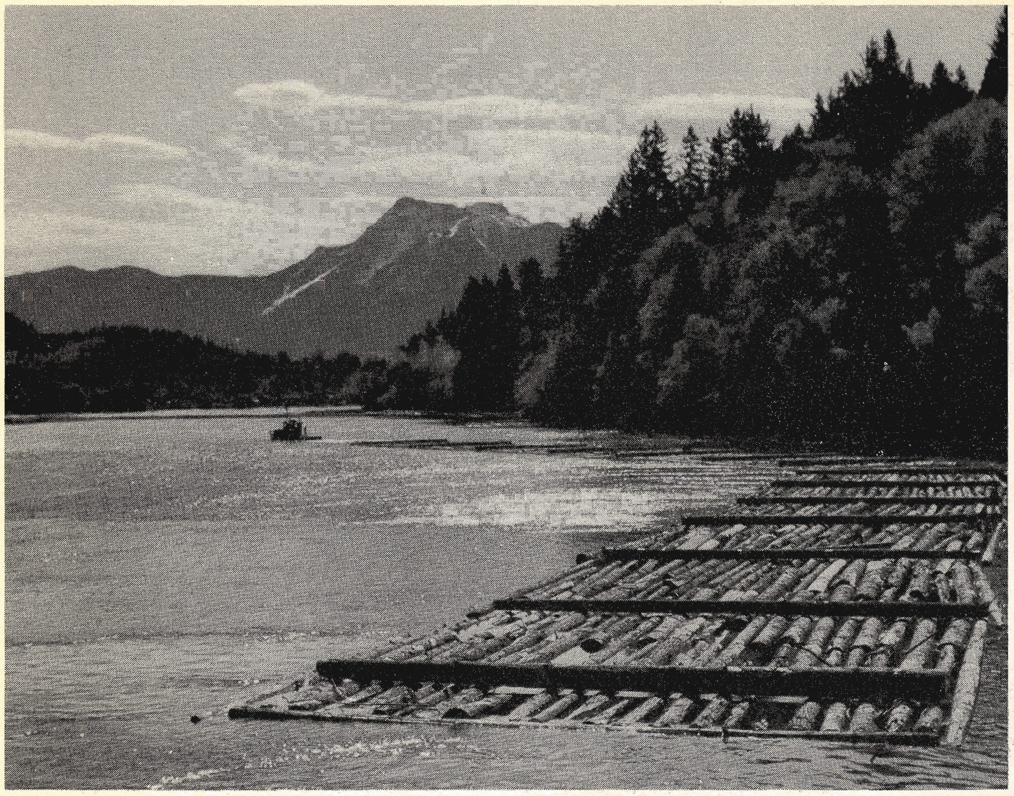
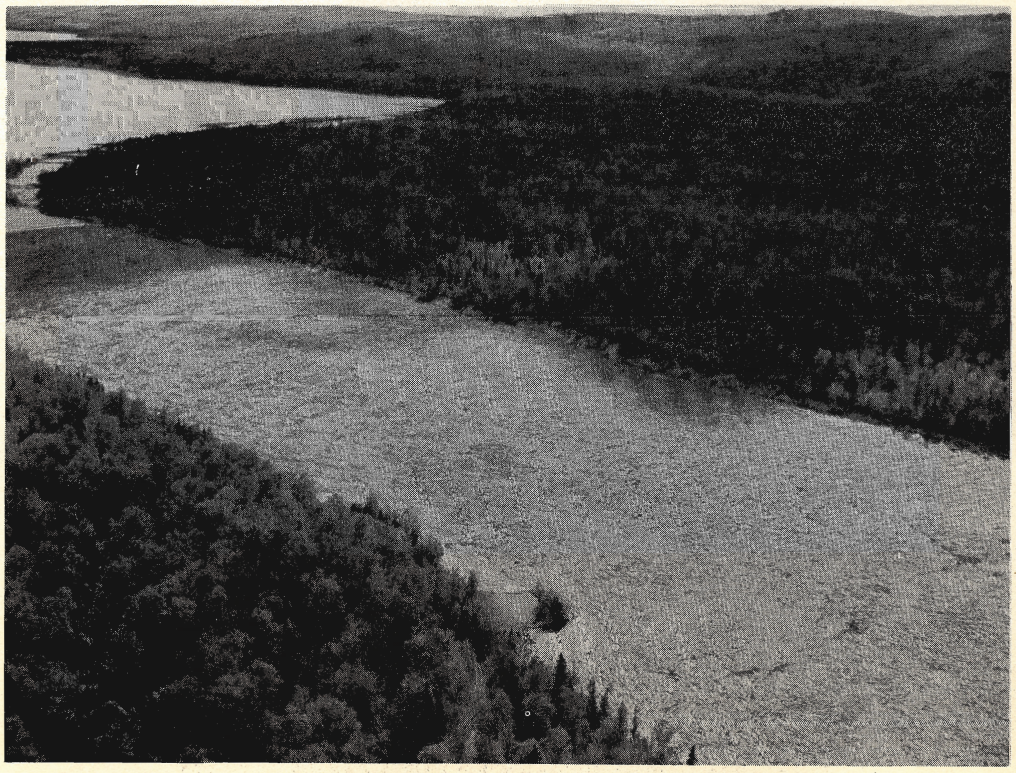
The Largest Log Buildings in the World are those of the Seigniory Club, Montebello, Que.


CANADIAN WOODS
their properties and uses



Raft of Sawlogs, British Columbia.



Pulpwood Floating to the Mills, Gatineau River, Quebec.

TIMBER, EAST AND WEST.

PULP, PAPER, AND RELATED PRODUCTS

by W. BOYD CAMPBELL

ACCORDING to ancient Chinese records, paper* was first made about the year A.D. 105 and was the invention of Ts'ai Lun. He discovered that, after various vegetable fibres were well macerated by pounding in water, they could be re-formed into a coherent sheet by simply draining off the water through a sieve and drying the layer of fibres held back. The materials found most suitable at the time were the inner bark of mulberry trees, young bamboo, and old linen or rope. To the extent that mulberry bark and bamboo were used by Ts'ai Lun, one may say that the first paper was made from wood.

The western world learned the art of paper-making through the Arabs who, among western nations, were the people most advanced in the arts and sciences during the Middle Ages. The Arabs themselves learned the craft from Chinese paper-makers whom they captured at the fall of the city of Samarkand, A.D. 751. Not having a supply of mulberry bark, the Arabs used linen rags. Knowledge of the art gradually spread from Arabia across Northern Africa, and was brought to Spain about 1150 A.D. by the Moors. In Europe, the art became first established through Southern France and Northern Italy, whence it spread to Germany (Cologne, 1320, or Nuremberg, 1390). The first paper-mill in England was established by John Tate in 1494, about the time of the discovery of America. Two hundred years later, paper-making was started in the New World by William Rittenhouse. At some time during the period when the art was spreading over the western world, the use of cotton as well as linen rags was introduced. Until the discovery of the modern wood pulp process, practically all paper produced in the western world was made from rags.

Whether or not the production of paper led in any way to the invention of printing, it seems certain that the development of the printer's art, commencing about 1490, led to a great expansion of the paper-making industry, an expansion which has continued to the present day. Aside from improvements in the method of application of power to the macerating, or "beating", part of the process, the next great advance was made about the year 1800, when the first paper-making machine was invented by Louis Robert in France and was financed and built by the Fourdriniers in England.

The double pressure of increased demand for paper caused by the printing art and spreading education, together with more rapid processes of making paper, threw a heavy load on the supply of raw material, which at that time was confined to rags. This shortage of supply led to many efforts to discover substitute materials, and, although many

*The word paper is derived from the papyrus used extensively in the ancient world, and notably in Egypt, before the invention of true paper. Very thin sections of the pith of the paper reed, *Cyperus papyrus*, were joined so as to produce sheets of a material admirably adapted for writing, drawing, or painting.

fibrous materials were tried after being treated in various ways, the first of these to meet with any very favourable reception was mechanical wood-pulp, first commercially produced in Germany by Voelter in 1844. The material had been earlier produced in Canada, near Halifax, by Charles Fenerty in 1838, but the invention was not commercially followed up.

In 1854, Watt and Burgess introduced a chemical process of producing a paper-making pulp from wood by cooking it under pressure with a solution of caustic soda. This process was further developed by Houghton in 1857. The caustic dissolved out most of the non-cellulose material of the wood, and left a pulp which could be readily bleached to a good white. In 1863, Tilghman invented the sulphite cooking process, by which the wood was cooked with a solution of calcium or magnesium bisulphite and sulphurous acid. This produced a pulp which for many purposes was sufficiently light in colour without bleaching, but which could be bleached if necessary. On account of the difficulties of handling the acid cooking liquor, this process came into use rather slowly, but the problems were gradually overcome and it is today one of the most widely used methods of producing chemical wood-pulp. In 1883, Dahl introduced a modification of the soda process, by which the wood was cooked with a solution of mixed sodium sulphide and caustic soda. This process could be applied to the long-fibred, highly resinous woods, such as pine, and resulted in the production of pulps which, though dark in colour, were of great strength.

The first paper-mill established in Canada was that at St. Andrews East, Quebec, in 1803. Groundwood was first made in Canada by Buntin at Valleyfield, Quebec, in 1866, a year before it was made in the United States. Soda-pulp mills were started at Windsor Mills, Quebec, in 1864 by Angus Logan; this was the second installation of the process in America. The first sulphite-pulp mill in Canada was established in 1888 at Cornwall, Ontario, by the Toronto Paper Co. Others were started at Merritton, Ontario, by Riordon, and at Hull, Que., by Eddy within a few months. In 1907, the soda-pulp mill at East Angus, Quebec, was re-designed by Bache-Wiig to use the new sulphate or kraft process, and was the first mill in America to use that process.

On account of the large stands of spruce and balsam fir in Canada, together with large supplies of easily developed water-power, Canadian production of wood-pulp has been largely groundwood, but in later years sulphite and kraft pulps have been produced to a rapidly increasing extent. Bleached sulphite pulp of the quality desired for the production of rayon by the viscose process is produced in Canada in quantities sufficient to supply about 40 per cent of the world's demand.

After the removal in 1911 of the tariff on newsprint going to the United States, the production of such paper in Canada rapidly increased, since the conditions for the manufacture of the principal component, groundwood pulp, were particularly favourable.

WOODS USED FOR PAPER PULP

THE woods used for paper pulp may be classified, from the point of view of pulp-making qualities, into three general classes. The first two of these are made up of the softwoods, or conifers, and the third consists of hardwoods. The softwoods, or conifers, have comparatively long fibres, which are particularly suitable for paper-making where strength is desired. They fall into two main classes, depending on the amount of pitch or resin they contain. The fibre of the hardwoods, or broad-leaved species, is relatively short, thus tending to make a bulky and weak sheet; it is consequently not in such general demand as that of the coniferous species. The three classes above referred to are the following:—

Class A —Long fibre, high resin: pines, Douglas fir.

Class B —Long fibre, low resin: spruce, balsam fir, hemlock.

Class C —Short fibre; hardwoods (chiefly aspen poplar).

Some woods are unsuitable because of difficulty in removing such materials as tannins or colouring matter. Thus, cedar is unsuitable for the latter reason, though it may be used for dark-coloured pulp. Oak and chestnut carry a considerable quantity of tannins, which, unless completely removed, react with iron salts to form dark-coloured compounds detrimental to the use of the pulp. In many cases also, the form of the available wood may have an influence on its usefulness. Sawdust, while of the same composition as the whole wood, is of little or no use for pulping because most of the fibres are too short. For chemical pulping processes, it is necessary that the wood be in pieces of fairly uniform size and character, so that the action of the cooking

liquors will not be too uneven. For this reason, many otherwise suitable forms of wood waste cannot be used to advantage, since it is difficult to produce from them chips of even size, or to separate the different species. Waste material from woodworking operations is frequently objectionable on account of dirt and bark, which are difficult to remove. The small supply of wood waste generally available in one locality is also a drawback, because a pulp mill must have a productive capacity of at least fifty tons per day to be an efficient unit. This calls for the consumption of about one hundred tons of wood per day, and such a quantity of suitable waste in one locality is rarely found.

On the other hand, a larger quantity of wood waste than is used at present might be utilized. Logs are frequently cut to lengths which do not saw to standard lengths of lumber. If the excess were cut off while still in the log, the ends could be barked and would form good pulpwood, except for the irregularity of length, which would add somewhat to the cost of handling. Under favourable conditions, other wood waste might be chipped to suitable size, the good chips being used for pulping, and the rest for fuel. Some pulp products, such as wallboard, do not require a high quality of pulp, and wood waste is frequently suitable for such uses. The whole question of using wood waste as a pulpwood supply depends on local circumstances which must be considered for each particular case.

The methods used for producing pulp depend on the kind of material available, the cost of power and chemicals, and the distance to market.

Groundwood

The cheapest of pulping processes is that used in making groundwood, and though the pulp is relatively poor in quality it finds very wide use. In this process, the wood, after being freed from bark, heavy knots, and bad spots due to decay, is mechanically reduced to pulp by the action of a grindstone. The character of the pulp and the power consumed in grinding vary according to the sharpness of the stone, the pressure with which the wood is forced against it, and the temperature at which the grinding is done. The temperature is controlled largely by the amount of cooling water supplied while grinding. This process yields almost the full weight of the wood as pulp. Owing to the action of the stone on the hard and soft portions of the wood, the pulp is a mixture of particles of all degrees of fineness from very fine, or flour, up to coarse slivers. The latter are removed by subsequent screening, and the "fines" are kept to a desirable proportion by control of the grinder conditions. The pulp contains practically all the original wood constituents, but on account of the large increase of surface and the high temperature produced at the grinding surface the pulp has much less durability than the wood from which it is produced. It is not used in papers where high quality is desired, but it is quite suitable for newsprint, boxboard, and low-priced papers generally. It constitutes from 75 to 90 per cent of ordinary newsprint. Its natural yellowish colour is neutralized in white papers by the addition of blue and violet dyes.

The woods generally used for groundwood are those listed in Class B above, that is, the low-resin softwoods such as spruce, balsam fir, and hemlock. Some jack pine is ground, but this species is not desirable on account of the resin content, which gives trouble in the paper-mill. Hardwoods may be ground and, on account of their greater density, often give high yields per cord; but because of their naturally short fibre they do not produce strong pulps.

The grinders used at the present time are of various sizes and designs, many of the old type of small, three-pocket grinders being still in service, as well as those of the large magazine type. Particular circumstances may dictate the use of one or other of the different designs. The small, three-pocket type consists of a stone of about 27 inches face by about 54 inches diameter revolving on a horizontal shaft. Spaced about the upper half of the stone are three pockets, each of which is fitted with a hydraulic ram. The wood, cut to 24-inch lengths, is put into these pockets and pressed against the stone by the ram, so that it is rapidly ground away to pulp. The temperature is kept under control by the use of cold-water sprays, which also wash away the pulp from the stone.

Many of the grinders installed in the last few years are of the large magazine type. In these, the stones are of about 54-inch face and take 48-inch wood, which is fed into a large hopper or magazine fitted with a chain or caterpillar on each side. The slow movement of this chain or caterpillar draws the wood through the magazine and forces it against the stone.

The power consumed in producing groundwood varies considerably according to the fineness of the pulp desired, the coarser kinds naturally requiring less power. Usually about 60 to 70 horse-power are required per ton of production per day, though this may vary from 50 to 90 horse-power. Mills range in size from those making 5 tons to those making 500 tons per day.

After leaving the grinder, the pulp is screened to remove the pieces of wood which have escaped grinding, and then given a second screening to remove the coarser parts of the pulp. The coarse rejects from the screens may be refined to good pulp by further treatment in a rod mill or other type of refiner, or may be given only a slight additional refining and used for making such products as wall-board, where coarseness of the pulp is no objection. The accepted pulp may be run into heavy sheets on what is known as a "wet machine", or may be kept in slush form if it is to be used immediately. Wet machines deliver the pulp in sheets which, when folded, are known as "laps" and contain about 30 per cent air-dry pulp. Usually these laps are further pressed in a hydraulic press, which brings the air-dry pulp content up to 50 or 60 per cent, and so makes for economy in freight and in storage space. On account of loss in paper-making quality if the pulp is dried, it is usual to ship it in this pressed condition, in spite of the necessity of paying freight on practically an equal weight of excess water. Pulp is marketed on the "air-dry" basis, which, by convention, allows a 10 per cent moisture content.

Most of the groundwood produced is used in newsprint, which is generally made in the same mill. A large tonnage is also used in the manufacture of container board and in the cheaper class of book and magazine papers, wrapping papers, toilet papers, and such products, where low price is more important than high quality. For some of these uses, particularly for board, groundwood comes into competition with old papers which can be readily reduced to pulp.

Chemical Wood Pulps

Wood substance consists of about 55 to 60 per cent of material that can be classed as "cellulose" and about 30 per cent of material classed as "lignin", the remainder being composed of various carbohydrates, resins, and tannins. Removal of the non-cellulose material by chemical action leaves a pulp of much higher grade than groundwood, and makes possible the production of wood-pulp papers of good strength, appearance, and durability. Treatments available for such removal with least damage to the cellulose are cooking with an acid solution of calcium or magnesium bisulphite, or with an alkaline solution of caustic soda or of caustic soda and sodium sulphide. The acid bisulphite, or "sulphite", process is applicable only to those woods that are low in resin and, in practice, is usually applied only to low-resin softwoods. The alkaline processes may be used on any wood, but usually hardwoods are cooked with caustic soda, and high-resin softwoods with a mixture of caustic and sulphide. This latter process is generally known as the sulphate, or kraft, process, because the soda compounds of the cooking liquor are obtained from sodium sulphate or salt-cake and the process is used for the production of kraft pulp, the term "kraft" meaning "strength".

Sulphite Process

The sulphite process is the most widely used of the chemical methods for pulping wood. Although the yield of pulp varies somewhat according to the severity of the treatment, it is usually slightly below 50 per cent by weight of the wood. The pulp is sufficiently light in colour to be used in many papers without bleaching, and produces papers of considerable strength. When the pulp is intended for bleaching, the cooking is carried somewhat further, with a consequently lower yield of pulp, which, however, bleaches easily to a high degree of whiteness.

The cooking liquor used in the sulphite process has a composition within the following range: 0.75 to 1.50 per cent sulphur dioxide combined as calcium or magnesium sulphite, and 3.0 to 6.0 per cent free sulphur dioxide, making a total sulphur dioxide concentration of 4 to 7 per cent.

This liquor is prepared by absorbing sulphur dioxide gas in water flowing over limestone, which dissolves in the acid solution. The gas is produced by burning sulphur. The amount of sulphur required may be as high as 270 pounds per ton of pulp, though efficient operation may reduce this to 200 pounds. The liquor so prepared is further enriched by sulphur dioxide recovered during the cooking process.

Cooking is carried on in vertical steel digesters having a capacity of from 3 to 20 tons of pulp. Because of the corrosive qualities of the cooking liquor, the digester is lined with acid-proof brick.

These digesters are from 10 to 17 feet in diameter and from 28 to 60 feet high. The wood, in the form of carefully prepared, clean chips about one inch square and ¼-inch in thickness, is put into the digester with the liquor and heated at a predetermined rate either by direct addition of steam or by steam in a heat interchanger through which the liquor circulates. Heating is continued until the temperature reaches a maximum of about 140°C. and covers a period of from 7 to 14 hours. The pressure inside the digester is limited to a maximum of 75 or 80 pounds by releasing liberated gas. This gas, being nearly pure sulphur dioxide, is used to enrich the liquor made in the limestone towers. At the end of the cooking period, the charge is blown out of the bottom of the digester into a blow-pit, where the liquor is washed from it, this residual liquor being usually run to waste.

The waste liquor contains a quantity of organic material, dissolved from the wood, approximately equal to the weight of pulp produced. Much study has been applied in efforts to find uses for this material, but only in late years have these been commercially successful to any great extent. The liquor contains certain fermentable sugars, and these can be coverted to ethyl alcohol or can be used as the food to produce yeasts of different varieties, some being suitable for human food, and some for cattle food. Another constituent of the liquor can be converted into vanillin, the essential part of vanilla flavouring. After some slight chemical change, the evaporated liquor may be used to assist in tanning leather. It may also be simply concentrated by evaporation to produce a cheap adhesive useful for such purposes as core-binding in foundry work. If magnesium bisulphite is used instead of the more common calcium bisulphite in the cooking liquor, it becomes feasible to evaporate the liquor and burn the residue, thus recovering heat, magnesium oxide, and sulphur dioxide. The heat recoverable in this way is about equal to that used in the cooking process.

Pulp made from spruce, balsam fir, or hemlock by the sulphite process is naturally light in colour and is used for many purposes without bleaching. Newsprint contains from 10 to 25 per cent of sulphite pulp, added to make up the deficiency in strength of groundwood. It is used in board, wrapping papers, and other papers which must be light in colour, though not a bright white, and which must possess a considerable measure of strength.

For papers which must be of a high degree of whiteness, or of a delicate colour which requires a white base for the dye, bleached sulphite pulp is used. When sulphite pulp is made for subsequent bleaching, the cooking is somewhat more severe, in order to remove more of the lignin compounds and so make bleaching easier. Bleached sulphite is suitable for all kinds of fine paper, except the very highest grades, which must be made of rag. It is particularly suitable for the bond papers used in most business stationery, because it produces a suitable combination of strength, finish, and colour, and a hardness for typewriter use, all at a moderate cost.

A sulphite-pulp mill is not a large consumer of mechanical power, but does require a considerable amount of steam. The cooking requires about 5,500 pounds of steam per ton of pulp produced. If the pulp is to be dried for shipment, a further 3,000 to 5,000 pounds of steam per ton is needed. Sulphite pulp is generally shipped dry, but may be handled like groundwood, that is, formed into laps on the wet machine and pressed to about 60 per cent dry for shipment. Most newsprint mills make their own sulphite pulp, as well as groundwood pulp, and save the expense of such preparation for shipment.

Soda Process

The soda process is the oldest of the chemical methods of making wood-pulp. It is used mainly for pulping hardwoods, particularly poplar. Beech, birch, maple, gum, chestnut, and other hardwoods are also pulped to a considerable extent. Owing partly to the action of the soda and partly to the natural character of the fibre of the hardwoods, the pulp tends to be soft, bulky, and without much strength. Although quite dark when cooked, it is readily bleached to a good white, and is practically always used in the bleached state. It is used in book and writing papers, which require to have a degree of softness and bulk, together with fine clear colour. In these it is generally used with sufficient bleached sulphite to add the necessary strength.

The digesters used for making soda pulp are usually smaller than those for sulphite and have a capacity of about 6 to 8 tons of pulp. The chips used are also somewhat smaller in size. The cooking liquor consists essentially of a solution of caustic soda of about 8 per cent strength. Cooking is complete in about 4 hours; maximum digester tempera-

ture is about 165°C., with a pressure of about 125 pounds per square inch. Cooking requires the presence of caustic to the extent of 20 to 22 per cent of the dry weight of the wood. Circulation systems are generally used on the digesters to ensure even cooking action, and heat interchangers are frequently used to avoid dilution of the cooking liquor by direct steam.

When cooking is complete, the contents of the digester may be blown into a blow-pit, as is done in the sulphite process, but the washing of the pulp must be so conducted as to recover as much as possible of the spent, or "black", liquor, which contains all the soda salts. For this reason, the contents of soda digesters are more generally blown into tall tanks known as diffusers, which make the pulp-washing process more efficient. The recovered black liquor is evaporated until it is barely liquid, and is then burned to produce "black ash", which contains the recovered soda in the form of sodium carbonate. This is washed with water to dissolve the carbonate, and the solution is then treated with lime to convert the carbonate to caustic soda. Losses of soda are made up by the addition of new carbonate or "soda ash" to the solution before causticizing. The amount of new soda ash required depends on the efficiency of the recovery of the old, but generally runs about 200 pounds per ton of pulp. About 900 pounds of lime are needed per ton of pulp. The yield of finished pulp is about 40 per cent of the dry weight of the wood. Soda pulp is usually dried and shipped in rolls or sheets. Canadian production is not large and there is little export of this class of pulp.

Sulphate, or Kraft Process

The sulphate, or kraft process is more widely used in Canada than is the older soda process, of which it is a modification. Properly speaking, it should be called the "sulphide" process, because the cooking liquor is a solution of mixed caustic soda and sodium sulphide in about the proportion of two to one. The term sulphate is used because the new soda is supplied as sodium sulphate or "salt cake" instead of sodium carbonate or "soda ash", but before use the sulphate is reduced to sulphide. In European literature, both this and the process using straight caustic soda are included frequently under the term "soda process".

This process applies particularly to the long-fibred, highly resinous woods such as the pines and Douglas fir, and produces pulps from which the strongest papers can be made, excepting, of course, those in the rope and rag classes, which are very expensive. In Eastern Canada, the wood used is largely jack pine, though some spruce and balsam fir are also included. On the west coast, Douglas fir and western red cedar are used. The fast-growing pines of the Southern States are the basis of a rapidly expanding kraft pulp industry in that region. Kraft pulp is normally of a rather deep brown colour, particularly if the cooking has been done in a manner to produce the strongest pulp. Such pulp has been considered until recently as being bleachable only with serious loss of strength, but increasing knowledge of the mechanism of bleaching reactions has shown that this is not so. By appropriate methods, it is possible to produce good white pulp having practically all the strength qualities of the brown kraft pulp from which it is made. When the cooking process is carried further than that used for the strong or kraft pulp, the product is lighter in colour and weaker, but can be bleached by the usual methods. Such pulp is generally termed sulphate pulp, to distinguish it from the strong or kraft pulp. This distinction, however, is not a definite one and is not always made.

Except for the difference in the composition of the liquor, the cooking is much the same as that described for the soda process. The liquor generally contains the equivalent of 8 to 10 per cent of caustic soda, about one-third being present as sodium sulphide. Cooking is done at temperatures of about 160 to 170°C., and pressures of 110 pounds per square inch, and is complete in about 4 hours. In this process, as in the soda process, dilution of the liquor is not desirable, and consequently circulation systems with external heating by heat interchangers are frequently used. The pulp, when cooked, is blown into diffusers, in which it is washed in a manner to recover as much as possible of the spent, or "black", liquor. The pulp is generally shipped in a damp condition containing about 60 per cent of air-dry pulp; to save freight charges it may be dried further, though this is detrimental to the further working up into paper.

As in the soda process, recovery of the soda is very important. The black liquor is evaporated in multi-stage evaporators, until it is as thick as can be handled. Further evaporation to a spongy solid is effected in a rotary dryer. On leaving the dryer, the evaporate is sent to a smelter along with the salt cake

furnished to make up losses. In the intense heat of the smelter (the waste gases from which are used to heat the rotary drier mentioned above), the organic matter is burned off, reducing the salt cake to sodium sulphide and leaving the remainder of the soda as sodium carbonate. This molten mixture runs to dissolving tanks, where, after solution, it forms the "green" liquor. Treatment of this liquor with lime converts the sodium carbonate to caustic soda, and produces the cooking, or "white", liquor. In some later installations the rotary dryer is not used, and the concentrated black liquor, to which more sodium sulphate has been added, is sprayed into a smelting furnace of special design, where the evaporation of water, the burning of organic matter, and the reduction of the sulphate to sulphide take place in one operation. The new salt cake required is about 500 pounds per ton of pulp produced.

The strong kraft and sulphate pulps find their greatest use in wrapping papers, bags, board, coarse envelopes, and such products as require much strength, but in which fine colour is not important. They can be dyed to deep colours which cover up the natural brown, but the resultant shades are always dull. In the last ten or fifteen years, the development of technique in bleaching kraft pulp has been much advanced, so that very strong white pulps can be produced. As kraft pulps can be produced from resinous woods, such as pine, which are not suitable for the sulphite process, this has greatly expanded the field of the kraft process and bleached kraft now competes with bleached sulphite for most paper-making purposes.

Miscellaneous Pulping Processes

In addition to the above-mentioned pulping processes, there are several others which, though not in general large-scale use, together produce a considerable amount of pulp. If we include in these the processes used in re-pulping old papers the proportion is very large indeed, especially in the United States.

Old papers are quite readily broken up to a pulp which can be re-used to advantage. Such re-pulping is almost entirely carried on as a part of the paper-making process. With the exception of container and similar board, which is required to be of high strength, nearly all paper-board manufactured in the United States and a large proportion of that in Canada is based on the re-use of waste paper. Such board is made on cylinder machines; the colour of the stock is of little consequence, and the pulping process need not include ink removal, as the final product may have a layer of "clean" stock on either or both surfaces to hide the greyness due to the ink. Pulping in such circumstances simply requires that the old papers be macerated in water until reduced to a mass of separated fibres.

When the old papers are to be used for white or bright-coloured new paper, the process is not quite so simple. The old papers to be used are carefully selected so that no papers containing groundwood or unbleached kraft are included. These would show up as dark-coloured fibres mixed with the white from the rest of the stock. The accepted papers, after being "dusted" dry to remove ordinary loose dirt as far as possible, are cooked in a dilute alkali, such as soda ash, and are usually macerated at the same time. This cooking need not be under pressure, so that open tanks of various designs are used.

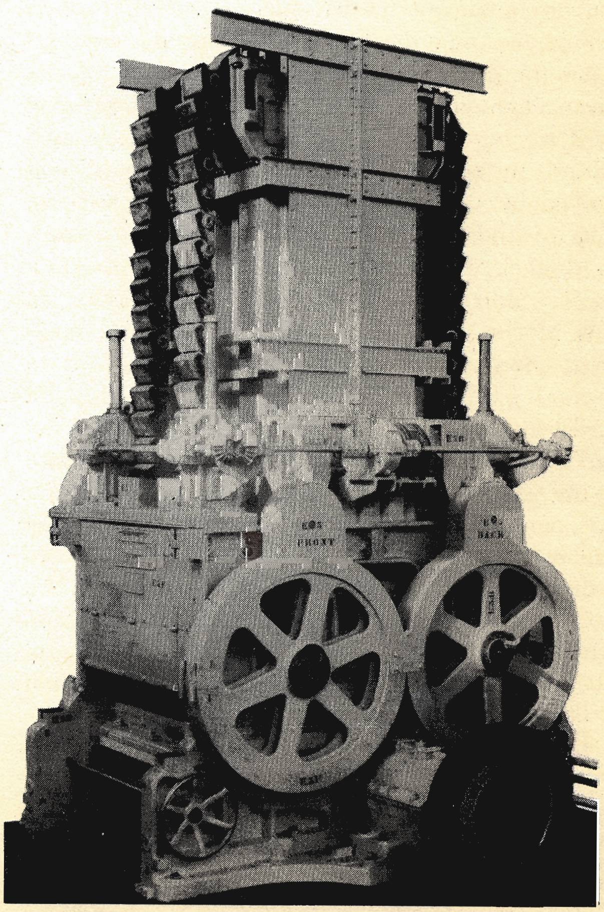


PLATE 104.—A 39½-inch Continuous Wood Grinder.

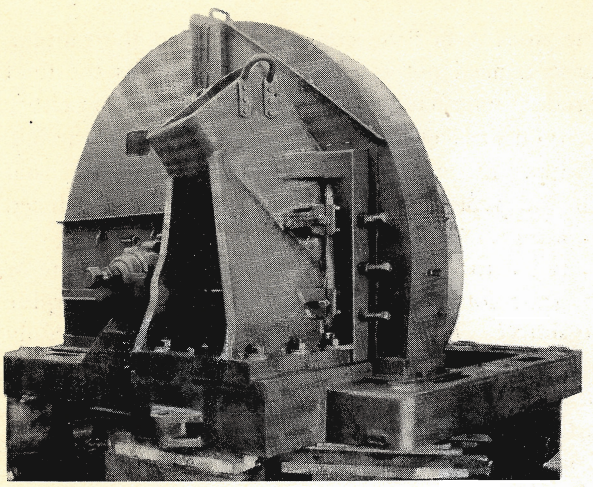


PLATE 105.—Pulpwood Chipper.

Following this cooking and maceration, the stock is washed to remove the dissolved inky material and also any fillers such as clay which were in the old paper stock. It is also screened to remove the wide variety of foreign matter, such as metal, rubber, cellophane, and the like, which pass the sorters.* After the first washing and screening, the stock is given a light bleach and is again washed before being used for new paper. Such de-inked stock is used mainly in magazine papers in lieu of hardwood pulped by the soda process. It imparts softness, opacity, and bulk to the papers in which it is used.

Another process in fairly widespread use makes a special pulp from miscellaneous wood waste. In this process, the wood is first reduced to small-sized pieces, corresponding to the chips used in normal pulping. These chips are carried by a screw conveyor into a pressure chamber, where they are steamed. The packing of chips at the entrance to the pressure chamber prevents escape of the steam. As the chips pass through this steam chamber, they are softened and, on reaching the outlet end, pass to a disc refiner which reduces them to a pulp. When operated in this way, the process produces a pulp which makes a sheet of great bulk and low strength. Such a sheet is of value as the basis for impregnation with tar or asphalt for building purposes.

In modifications of the above process, the reaction chamber is made longer, and one or other of the usual pulping chemicals is added. Partial cooking of the chips takes place, so that the pulp after disintegration is more like normally cooked pulps, except that it is "raw" and is usable only for coarse grades of paper. Other "semi-chemical" pulps are made by using the ordinary cooking processes, stopping the cook before completion, and finishing the disintegration of the chips by mechanical means. The object is to get a high yield of pulp which is sufficiently pure for the particular purpose in mind. One of these processes uses as cooking medium a solution of sodium sulphite and sodium bicarbonate to produce a high-yield pulp of good colour.

*The variety of such material is astonishing; paper clips and staples from magazines are of frequent occurrence, while coins and pieces of sheet metal, such as copper printing plates, are not uncommon. In one known case, diamonds to the value of several thousand dollars were found in old papers; they did not pass the sorters, however.

PAPER-MAKING

THE art of paper-making depends essentially on the fact that, when a layer of wet cellulose fibres is dried, the fibres adhere to each other with considerable tenacity. This property of cellulose fibres obtains only when they are wet with water; other liquids will not serve. Naturally, the extent of adhesion depends in part on the amount of surface in contact; large and stiff fibres will touch at only a few places, whereas fine and flexible fibres will be in contact for a great part of their length. Any treatment which increases the area of contact of fibres with each other will, therefore, other things being equal, produce a stronger paper. Other factors involve such matters as the length of the fibres and their intrinsic strengths. Long fibres distribute the stresses over more area than short ones, and stronger fibres naturally mean a stronger paper.

Paper-makers have, from the earliest times, increased the strength of their papers by treatment of the fibres so as to increase the surface. This is done by some form of mechanical action, by which the fibres are pounded or bruised while in water. All the natural fibres are built of smaller units, or fibrils, which are arranged in the fibre in a characteristic manner, one structure for cotton, another for linen, and another general type for wood fibres. When wet with water, these fibrils may be loosened from each other, or even broken out from the parent fibre, by such mechanical action as pounding or severe bending. Such a result is produced in the paper-maker's beater. At the same time, some fibres are reduced in length, and a part of the paper-maker's art is to control the relative degree to which these two effects are produced.

Pulp Beaters

The beater is a simple piece of mechanism, consisting of a large oblong tub with a partition, or "mid-feather", extending part of the way down the middle. This partition divides the tub so that it becomes an oval channel, and in this channel is circulated a suspension of the pulp in water. On one leg of the channel is a roll rotating on a horizontal axis and practically filling the channel. This roll is fitted with a large number of heavy knives at right angles to its surface and extending parallel to the axis of the roll. Below the roll is a bed-plate similarly fitted with knives. The rotation of the roll forces the pulp between the roll and the bed-plate, and the combined action of the two sets of knives causes a more or less severe cutting or bruising of the fibres, at the same time circulating the whole charge around the tub. The concentration of pulp is usually about five per cent, though it may be anywhere from four to eight per cent. At this concentration the mass has a consistency similar to that of oatmeal porridge, and circulates around the beater at a velocity of about twenty feet per minute. Regulation of the space between roll and bed-plate controls the relative amount of bruising and cutting. Bruising, up to a certain degree, increases the strength of the paper, while some amount of cutting action is generally desirable to aid in the formation of a sheet of even density throughout.

By controlling the action of the beater, the older paper-makers produced from rags, the one raw material available, papers having a range of character varying from blotting-paper to a parchment-like sheet. Some rags were more suitable for certain papers than were others but, in the main, paper was "made in the beater". Today, with a much greater range of pulps available, beating is not of quite such importance as formerly, but the beater is still one of the most important machines in a paper-mill.

In addition to control of the character of the paper through the beating action, further control is exercised by the blending of different kinds of pulp. Every variety of pulp has characteristics which are valuable in certain circumstances, and a proper blending and treatment of these enables the production of paper of desired properties at minimum expense.

Newsprint

In Canada, the manufacture of newsprint constitutes the greater part of the pulp and paper industry, owing to the fact that most newsprint is best made of a mixture of groundwood and sulphite pulps, the groundwood being 75 to 90 per cent of the whole. The groundwood used not only lowers

Plate 106.—Pulp Beater.

the cost, but improves the printing quality by making the paper more opaque and more receptive to printing inks. On account of the proximity of cheap power to suitable wood in Canada, the production of groundwood pulp can be carried on at low cost. The large and easily accessible market in the United States furnishes the outlet for the sale of a vast quantity of this class of paper. In the making of newsprint, as carried on today in Canada, the beater is not used, the character of the groundwood constituent being controlled by adjustments in the grinding. The sulphite pulp is added partly because its longer fibres give greater strength to the wet pulp, resulting in less trouble on the paper machine, and partly because it contributes a measure of strength which would otherwise be lacking in the finished paper. Improvements in the quality and uniformity of groundwood, through increased technical control and better methods of test, have been for several years gradually reducing the percentage of the more expensive sulphite pulp required.

Other Papers

The usual composition of other common varieties of paper is as follows:

1. Wrapping, strong, dark-coloured—*kraft.*
2. Wrapping, light-coloured—*sulphite, bleached or unbleached; bleached kraft.*
3. Wrapping, low-grade—*unbleached sulphite or kraft, with groundwood.*
4. Hangings (wall-paper)—*groundwood and sulphite.*
5. Book and cheap writing—*soda (or repulped paper) and bleached sulphite with clay or other filler.*
6. Better-grade writing and typewriter papers—*bleached sulphite or kraft, well beaten; low grades, as former, with some groundwood and unbleached sulphite.*
7. High-grade writing—*bleached sulphite or kraft and rag, or all rag.*
8. Low-strength box-board—*old papers, groundwood with unbleached sulphite or kraft.*
9. High-strength container board—*low-grade core as in (8) with strong kraft outer layers. Some grades solid kraft or kraft and groundwood.*
10. Wall-board—*groundwood or groundwood and coarse screenings of other pulps.*
11. Pressed pulp articles (pie-plates, etc.)—*groundwood.*
12. Tissues—*bleached or unbleached sulphite or kraft, with groundwood in lower grades.*

The Paper Machine

Besides the selection and blending of pulps, and the treatment of them in the beater or its equivalent, paper-making involves conversion of the pulp suspension into dry paper. The first essential is to get an even layer of the wet pulp. The first step in this direction is to dilute the heavy suspension with enough water for the fibres to move about freely. This requires about two hundred parts of water to one part of pulp. This thin suspension is then allowed to flow, in a carefully regulated stream, on to a moving belt of woven wire. As this wire screen (known in the mill as "the wire") moves along, the water drains away, leaving the pulp in an even layer. Although drainage of water through the wire is assisted by suction, a great deal remains. The sheet of wet pulp leaving the wire contains four or five times as much water as pulp, but is sufficiently strong to be pulled away from the wire and taken up by another belt, this time of wool, called a press felt. On this wool blanket it travels between heavy press rolls, which remove more water. By the time the sheet has passed the press rolls, of which there may be two, three, or more sets, the water has been further reduced, so that the sheet now contains only about two or two and a half pounds of water per pound of pulp. The remaining water cannot be removed mechanically, but must be evaporated. This is done by running the paper over a number of steam-heated cylinders. Leaving the drying section of the paper machine, the sheet is passed through the calender stack, made up of a number of polished steel rolls, between which the paper is pressed to give surface smoothness.

Variations in this procedure are found in machines designed to produce special papers. Thus, in a machine for making tissue paper, the sheet, after being formed on the wire, is not strong enough to carry its own weight over the distance from the end of the wire to the press felt. The machine is therefore arranged so that a wool blanket, or "felt", is brought into contact with the sheet while it is still on the wire, and the two leave the wire together. For some classes of paper, the drying is completed on a single large dryer. In such cases, the side in contact with the dryer is highly glazed, while the other is rough. Papers made in this way are known as M.G. or machine-glazed papers. Many heavy-weight papers or boards are formed on what are known as cylinder

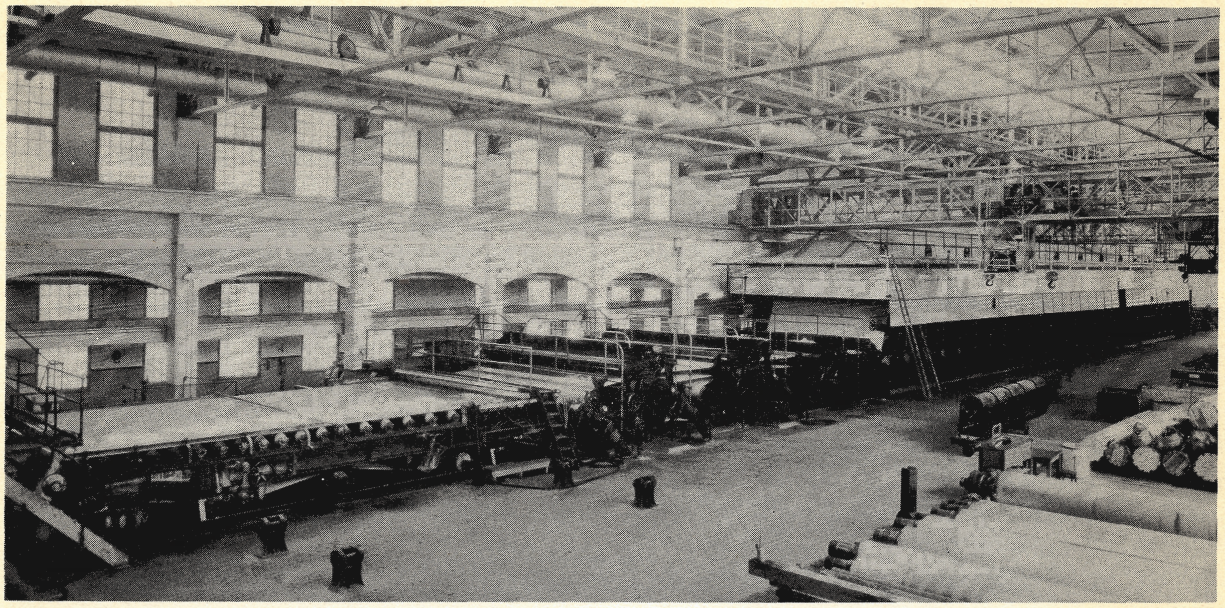
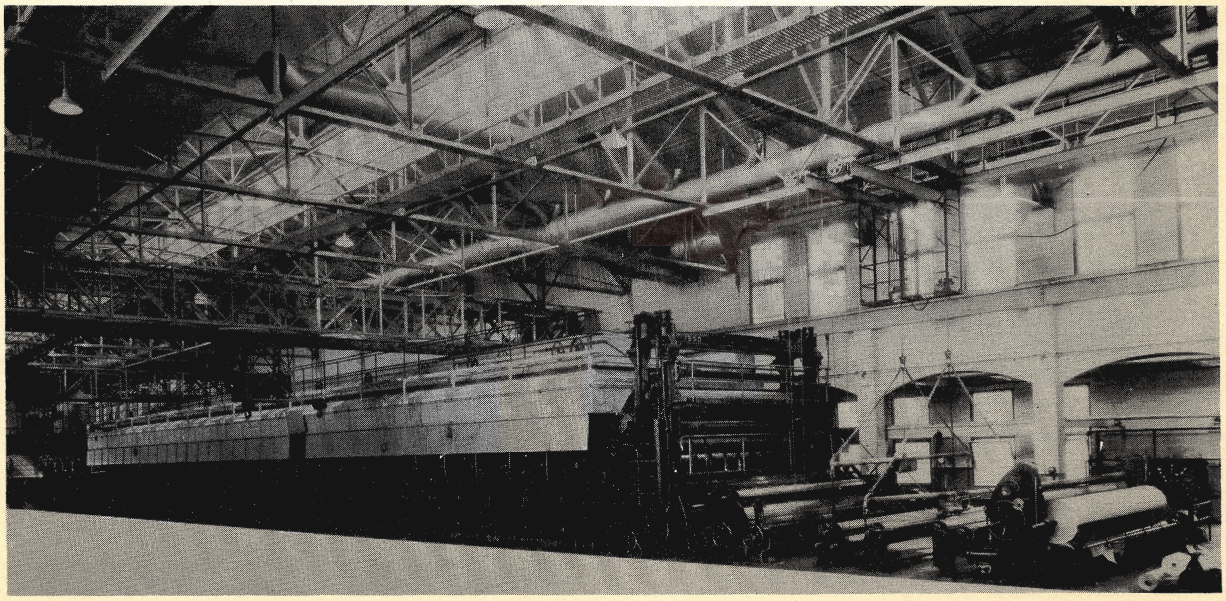


PLATE 107.—Wet End of 226-inch High-speed Newsprint Machine, showing Fourdrinier, Suction Couch Roll, and First and Second Press Rolls.

machines. Instead of a single belt of wire screen, a machine of this type forms the sheet on a number of screen-covered cylinders running partly submerged in the dilute stock. Each of these cylinders picks up a layer of pulp independently and a felt running over all the cylinders picks up these layers in succession and combines them into a single heavy sheet which is pressed and dried as described above.

PLATE 108.—Dry End of 226-inch High-speed Newsprint Machine, Showing Dryer Section, Calender, Reel, Unwinding Stand, and Winder.



SECONDARY PAPER PROCESSES

Coated Paper

MANY papers undergo secondary treatments for special reasons. The most common of these secondary processes is that of coating, which is used extensively for paper requiring a particularly smooth surface. Such a surface is required for printing illustrations from fine half-tone plates. Coated paper is formed from a base paper of a character similar to a magazine book-paper by covering one or both surfaces with a pigment* held to the surface with some adhesive. The most commonly used adhesive is a solution of casein, though other glues and starch are used to some extent.

The pigments mostly used are china-clay, satin white, blanc fixe, and Paris white. The pigment suspended in the adhesive solution has about the consistency of paint and is brushed on to the sheet in an even layer, and dried. On passing the dried sheet through a calender stack the surface is made very smooth and has a high gloss. The pigments mentioned above are all very pure whites, but colours can be added to produce practically any desired shade. Since the base paper can be completely hidden by the coating, such papers may present a very attractive surface and are much used for fancy wrappings on this account, even when the smooth surface is not essential for the printing used.

In recent years, a grade of coated paper known as "machine-coated" has become an important product. While inferior in some respects to the older "brush-coated" it has merits of its own, including a lower price. It is made by applying a starch-clay mixture to the paper while the latter is still on the paper machine. There are several methods of doing this. One of them applies the coating by rollers, as if printing a white ink all over the surface. Such papers are used in magazines which make a special point of publishing half-tone illustrations.

Waxed Paper

Waxed paper is another example of a paper which has received a secondary processing. The base paper is run through a bath of melted wax; according to the temperature of the wax bath and the porosity of the paper, it may be made to absorb the wax almost entirely into the sheet, or to leave a considerable layer on the surface.

*The word pigment, which usually connotes any colour other than white, in the literature of paint and paper includes white also.

Parchment Papers

Parchment papers are made by passing a base paper of bleached pulp through a bath of strong sulphuric acid. If left in such a bath, the cellulose would dissolve; but, when the sheet is passed through the bath quickly, the cellulose is only made gelatinous and, on washing, the gelatinous material binds the whole together. When dried, the sheet is very resistant to grease, and has almost the same strength when wet as when dry. Such papers are extensively used for such purposes as wrapping butter and, in heavy weights, for fancy articles, such as lamp shades, and for formal documents, such as diplomas. An imitation of this paper can be made directly on the paper machine by using pulp which is heavily beaten. Such papers are known as imitation parchments, or grease-proofs, and are used for packing many dry foods which are of an oily nature, such as biscuits and nuts.

Cellulose Products

In addition to the uses of cellulose pulps in products which may be called paper, in that the fibres make up the finished article, there are many materials based on cellulose in which the fibre is completely transformed, rayon being the most important. In many such uses, the cellulose ordinarily used is not wood pulp, but, since the cellulose is identical, there is no inherent reason why wood pulps could not be used; the chief obstacle at present is that difficulties of purification and handling have not yet been commercially overcome.

Rayon

Rayon is a term adopted by the manufacturers of synthetic cellulose textiles to designate their products and give them an identity of their own; the former designation "artificial silk", is admittedly a misleading term. Of these synthetic textiles, by far the largest amount is made by the viscose process from bleached sulphite pulp. The pulp is treated first with a strong solution of caustic soda, in which it swells to some extent and absorbs the solution. The damp mass, broken up into small crumbs, is then exposed to fumes of carbon bisulphide. This reacts

with the cellulose and soda to form, on addition of water, a thick solution of cellulose, known as "viscose". The solution, which has the appearance and consistency of a syrup, is filtered to remove all solid particles, and is then forced through fine holes into an acid bath. On passing into the acid, the fine streams of viscose solution are coagulated into fine threads which, after being twisted into yarns, washed, and dyed, may be woven or knit into textiles.

Another variety of the same material is cellophane To produce this, the cellulose solution, instead of being forced through small holes, is forced into the acid bath through a long narrow slot, so that it coagulates as a sheet. Cellophane, while it can resist the passage of air, does not prevent the passage of moisture. By coating it with an extremely thin layer of nitro-cellulose or similar material it may be converted, without change of appearance, into moisture-proof cellophane, superior for many purposes.

The viscose process is not the only method of producing rayon; there are other methods of dissolving cellulose and spinning threads from it. It may be dissolved in a mixture of copper oxide and ammonia, to form a solution which may be forced through fine holes, and converted into thread by the coagulating action of an acid bath, in much the same manner as in the viscose process: alternatively, the cellulose may be converted into cellulose nitrate by treatment in a bath of mixed nitric and sulphuric acid; the cellulose nitrate may be dissolved by acetone or certain other solvents, the threads being formed by evaporating the solvent from fine streams of the thick solution. The threads of cellulose nitrate are highly inflammable, so they are treated in sodium sulphide solutions, which cause the nitrate to revert to cellulose, while maintaining the thread form.

The processes mentioned produce threads of cellulose. There is another process in which the final thread is not cellulose, but a compound of it with acetic acid, namely, cellulose acetate. In this process, the cellulose (usually cotton) is converted to cellulose acetate by treatment with acetic anhydride and acetic acid. The acetate is dissolved in acetone, and threads are drawn from the thick solution. As the acetone evaporates, the thread acquires solidity, and may be twisted to yarn for weaving or knitting. Unlike the nitrate, cellulose acetate is not highly inflammable, and fabrics made from it have an advantage over those made from reverted cellulose in that they are weakened to a lesser extent when wet.

Additional Uses for Wood Cellulose

In addition to their use in rayon, cellulose nitrate and cellulose acetate are used with other materials to form films for photographic uses, as the basis of quick-drying paints and lacquers, and for moulded articles such as the celluloid products. Cellulose nitrates of higher nitrate content are widely used in a variety of explosives.

CELLULOSE MATERIALS OTHER THAN WOOD

CELLULOSE may be obtained from a large variety of vegetable sources, and circumstances may make some of these heavy competitors with wood. Cereal straws contain 35 to 40 per cent of cellulose, and may be converted into paper pulp which is suitable for many uses. A cheap straw pulp is made by simple cooking of straw with lime; this is used for corrugated board to be placed between two stronger boards to make the built-up board used for shipping containers. By other conversion methods it may be made into white pulps. A large proportion of papers made in Britain contain some esparto pulp, which is made from esparto grass. In America, this is replaced by soda pulp in papers of similar character.

Many attempts have been made to use corn stalks and bagasse (refuse from sugar cane mills) as a pulp material. Although these are successfully used for making such coarse products as wall-board, it is difficult to get them sufficiently clean to make white pulps. The presence of a large percentage of pith cells in these materials tends to give a very "tinny" character to paper made from them and also restricts their use.

The short cotton hairs remaining on cotton seed after removal of the long staple cotton are available in large quantity and when purified and bleached constitute an active competitor of wood-pulp for many rayon processes and to some extent for paper. The material is generally used for cellulose nitrate and acetate and frequently in fine writing and blotting paper.

Woods not now used to any great extent may be used more extensively in the future for wood-pulp production. Bamboo, which botanically is a grass, may be pulped very successfully, and as it grows very rapidly it may come into use if the wood-pulp supply gets low.

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NEWSPRINT.
The value of paper and related products turned out by Canadian mills in 1948, amounted to nearly $600,000,000.

Explanation of Tables

THE following tables are intended to provide information regarding mechanical properties of Canadian woods clear of defects, and of timbers in structural sizes and grades, as well as data of value in computing safe allowable loading in structures.

Where specific structural grades are mentioned, as in Tables 2, 3, 14, and 15, the grades referred to are those which have been adopted by the Canadian Standards Association, and are defined in the C.S.A. Specification for Structural Timber (A43-1937) presently under revision.

While structural grades have been established for certain Canadian species, for others no such grades exist. However, timbers of the proper size, graded in accordance with the requirements of this specification, and assigned the working stresses shown in Table 2,* will be of sufficient strength to carry the loads required, provided the general design of the structure is correct.

Table 3

In computing Table 3, Safe Loads for Wooden Columns, the following procedure was adopted:—

(1) For columns where the ratio of unsupported length to least dimension did not exceed 10, the allowable working stress was obtained by applying a suitable factor of safety to the maximum crushing strength in compression parallel to the grain.

(2) For columns, the ratio of whose unsupported length to the least dimension was greater than 10, the following formula was used until the reduction in the allowable stress equalled one-third the stress for short columns:—

Formula:

$$\frac{P}{A} = S\left[1 - \frac{1}{3}\left(\frac{L}{Kd}\right)^4\right]$$

where $P =$ total load in pounds;

$A =$ area in square inches;

$\frac{P}{A} =$ unit compressive stress;

$S =$ safe stress in compression parallel to grain for short columns;

$L =$ unsupported length in inches;

$d =$ least dimension in inches;

$K =$ the $\frac{L}{d}$ at the point of tangency of the parabolic and Euler curves, at which $\frac{P}{4} = \frac{2}{3}S$

The value of K for any species and grade is

$$\frac{\pi}{2}\sqrt{\frac{E}{6S}}$$

where $E =$ modulus of elasticity.

*Note: Since the publication of C.S.A. Specification A43-1937, further consideration has been given by the Forest Products Laboratories to safe allowable working stresses for Canadian timbers. As a result, some changes have been made in the safe allowable working stresses previously recommended by the Laboratories. The revised recommended working stresses are shown in Table 2 of the Appendix.

(3) For columns of still greater length, the Euler formula below, which includes a factor of safety of 3, was used:

$$\frac{P}{A} = \frac{\pi^2}{36}\frac{E}{\left(\frac{L}{d}\right)^2}$$

(4) Columns where limited in slenderness to $\frac{L}{d} = 50$.

(5) Round columns—See page 120 and Specification A43-1937 (p. 38, par. 35).

Tables 8 and 9

With respect to Tables 8 and 9, the values given are the actual loads in pounds, uniformly distributed, which beams of the size and safe allowable stress indicated will support over a span of one foot. For the various species having the safe allowable working stresses indicated, consult the column in Table 2 headed "Stress at Extreme Fibre". The resistance of the beam to longitudinal shear should be checked to ensure that it is within the safe limits prescribed (Tables 10 and 11).

Tables 12 and 13

The values given in Tables 12 and 13 are the deflections in inches which will occur in joists and beams of the dimensions and moduli of elasticity indicated, when carrying a uniformly distributed load of 1,000 pounds over a span of one foot. To obtain the deflection in inches for a certain size of a particular species of timber, with a uniformly distributed load over a certain span, first obtain from Table 2 the value for the modulus of elasticity of the timber, then multiply the value given in these tables under this modulus and opposite the cross-sectional dimension by the cube of the span and by the load in thousands of pounds.

Table 16

From the values given in Table 16, it is possible to select the most suitable sizes of joists of any species for any condition of floor load up to 150 pounds per square foot on 12- or 16-inch joist spacings, and for floor spans of from 8 to 25 feet.

To ascertain, for example, what size of joist of Structural C.S.A. grade white pine is required to support a floor load of 100 pounds per square foot, spaced at 12 inches, over a span of 16 feet, from Table 2 obtain the safe allowable working stress (stress at extreme fibre) for Structural C.S.A. grade white pine, viz., 800 pounds per square inch. In Table 16 will be found a value of 230,400 corresponding to a load on floor of 100 pounds per square foot, a distance between joists of 12 inches, and a joist span of 16 feet.

Divide this value by the working stress for structural white pine from Table 2, namely, 800 pounds per square inch:

$$\frac{230{,}400}{800} = 288$$

Under the column bd^2 (Table 16) for either full or dressed sizes may be found suitable sizes (cross-sections) of joist to carry the required load. It will be seen that a number of different sizes may be used, viz:

2″ x 12″ (full size) = 288
3″ x 10″ (full size) = 300
1⅝″ x 13½″ (dressed size) = 296.16

MECHANICAL AND PHYSICAL PROPERTIES OF WOODS GROWN IN CANADA (GREEN CONDITION)

TABLE **1A**

SPECIES	PLACE OF GROWTH OF MATERIAL TESTED	Rings Per Inch	Summerwood (Per Cent)	SHRINKAGE From Green to Oven-dry, Based on Dimensions when Green, (per cent) Volumetric	Radial	Tangential	SPECIFIC GRAVITY Basic: Volume Green Weight Oven-dry	Oven-dry: Volume Oven-dry Weight Oven-dry	Weight Per Cubic Foot as Tested (lb.)	Moisture Content Based on Weight Oven-dry (Per Cent)	STATIC Fibre Stress at Proportional Limit (p.s.i.)	Modulus of Rupture (p.s.i.)*	Modulus of Elasticity (1,000 p.s.i.)
(1)	(2)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Cedar, Eastern White	Que., N.B.	30	26	6.3	1.7	3.6	0.30	0.31	34	80	2000	3900	520
Cedar, West Red	B.C.	15	27	7.8	2.1	4.2	0.31	0.34	29	51	3100	5300	1050
Cedar, Yellow	B.C.	38	18	9.3	3.7	6.0	0.41	0.46	34	34	3600	6500	1300
Douglas Fir (Coast)	B.C.	20	39	12.0	5.0	7.9	0.46	0.52	39	38	4700	7700	1700
Douglas Fir (Mountain)	B.C., Alta.	20	30	11.5	4.5	7.3	0.43	0.47	36	33	4200	7100	1390
Douglas Fir (Second Growth)	B.C.	6	39	11.8	4.8	8.0	0.44	0.49	40	47	4200	7400	1550
Fir, Amabilis	B.C.	14	23	12.8	4.3	9.1	0.36	0.41	38	70	2900	5500	1370
Fir, Balsam	Que., Man., Sask.	9	25	10.8	2.7	7.5	0.33	0.37	46	123	2800	5300	1140
Hemlock, Eastern	N.B., Que.	25	29	10.1	3.1	6.1	0.38	0.43	47	98	3600	6800	1180
Hemlock, Western	B.C.	19	32	12.9	5.3	8.5	0.41	0.47	44	71	4100	6900	1470
Larch (Tamarack)	Que., Man.	18	28	11.3	2.8	6.2	0.48	0.54	48	59	2900	6500	1150
Larch, Western	B.C.	22	32	14.0	5.1	8.9	0.53	0.67	51	54	5000	8700	1650
Pine, Jack	Ont., Man., N.B., Sask.	14	24	9.7	4.0	5.9	0.42	0.46	40	51	3500	6300	1170
Pine, Lodgepole	B.C., Alta.	25	23	11.4	4.7	6.8	0.40	0.45	39	58	3000	5700	1280
Pine, Red	Ont., N.B.	16	24	9.6	3.5	5.9	0.39	0.42	52	114	2800	4900	1040
Pine, Western White	B.C.	19	24	10.7	3.7	6.8	0.35	0.40	36	61	2900	4800	1180
Pine, Ponderosa	B.C.	26	16	10.5	4.6	5.9	0.44	0.49	47	70	3300	5700	1140
Pine, White	Ont., N.B., Que.	15	23	8.4	2.4	6.3	0.37	0.39	46	100	3000	5100	1180
Spruce, Black	Que., N.B., Man., Sask.	19	25	11.5	3.7	6.9	0.40	0.45	37	49	3100	5800	1290
Spruce, Engelmann	B.C.	17	20	11.5	4.2	8.2	0.37	0.42	36	57	3200	5700	1250
Spruce, Red	N.S., N.B.	17	23	11.9	4.0	8.0	0.38	0.43	35	49	3000	5900	1320
Spruce, Sitka	B.C.	13	22	11.7	4.6	7.8	0.35	0.39	31	44	3100	5400	1370
Spruce, White	Que., N.B., Man., Sask.	13	22	10.8	3.4	6.4	0.35	0.38	38	75	2800	5100	1150
(1)	(2)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Alder, Red	B.C.	6		11.6	4.2	7.0	0.37	0.42	46	101	3500	6300	1200
Ash, Black	Ont.	17		13.9	4.3	8.2	0.48	0.54	56	87	3000	6500	1290
Ash, Green	Man.	23		10.9	3.9	5.4	0.47	0.52	47	59	2200	4900	730
Ash, White	Ont., N.B.	10		13.2	4.3	7.2	0.58	0.65	53	47	4000	8300	1430
Basswood	Que.	10		18.4	6.7	9.3	0.36	0.42	48	115	2700	5000	1070
Beech	Que., N.B.	13		17.4	5.2	10.2	0.59	0.70	61	67	4200	9100	1500
Birch, White	N.B., Man., Sask.	13		14.1	5.2	7.2	0.51	0.59	56	76	3300	6900	1510
Birch, Western White	B.C.	10		15.1	6.4	9.7	0.50	0.59	54	72	3800	7300	1610
Birch, Yellow	Que., N.S., N.B.	19		15.5	5.8	7.1	0.56	0.66	57	63	3900	8200	1540
Butternut	Ont.	9		9.6	2.8	4.9	0.37	0.40	45	96	2500	5000	950
Cherry, Black	Ont.	8		12.9	4.0	7.1	0.50	0.58	47	51	3600	7800	1450
Chestnut	Ont.	9		10.0	2.8	5.3	0.43	0.47	54	102	3400	7200	1120
Elm, Slippery	Ont.	12		15.5	4.4	9.8	0.54	0.64	58	72	3900	8200	1260
Elm, Rock	Ont.	27		13.6	5.0	9.2	0.60	0.68	58	56	4600	9200	1360
Elm, White	Ont., Que., Man.	14		15.1	4.6	8.6	0.51	0.61	62	96	3400	7200	1120
Hickory, Bitternut	Ont.	12		17.8	6.5	10.2	0.62	0.76	60	55	4000	9900	1710
Hickory, Shagbark	Que., Ont.	15		17.1	4.9	8.4	0.65	0.78	63	56	4500	10000	1500
Ironwood	Que.	14		17.9	4.8	8.0	0.65	0.78	60	47	5100	10400	1800
Maple, Broadleaf	B.C.	9		12.1	4.3	7.8	0.47	0.53	50	71	4300	8100	1310
Maple, Manitoba	Man.	11		13.9	3.9	7.4	0.41	0.49	56	121	2900	5400	910
Maple, Red	Ont.	13		12.4	3.6	6.0	0.51	0.59	59	86	4300	8500	1610
Maple, Silver	Ont.	9		12.8	3.2	6.4	0.46	0.51	45	58	3300	6800	1330
Maple, Sugar	Que., N.B.	21		15.8	4.7	8.6	0.60	0.70	59	59	5100	10100	1680
Oak, Black	Ont.	9		13.3	3.8	6.9	0.60	0.68	63	69	4500	9400	1610
Oak, Bur	Man.	26		13.9	4.2	5.4	0.60	0.70	62	65	2700	6200	790
Oak, Red	Que., Ont.	10		11.9	3.6	6.7	0.58	0.65	63	74	4200	9200	1530
Oak, White	Ont.	20		16.6	4.7	6.0	0.65	0.77	62	53	3700	8800	1530
Poplar, Aspen	N.B., Man., Sask.	12		11.7	3.6	6.6	0.38	0.42	53	123	2900	5500	1350
Poplar (Largetooth Aspen)	Ont.	7		11.9	3.2	6.7	0.39	0.44	48	99	2800	5400	1110
Poplar, Balsam	Ont., Man.	13		11.6	3.9	6.4	0.37	0.42	48	107	2600	4900	1160
Poplar (Cottonwood)	Ont.	3		11.8	3.1	7.8	0.36	0.39	58	157	2600	4800	890
Walnut, Black	Ont.	6		13.7	4.8	7.7	0.54	0.63	57	69	4400	8700	1540
(1)	(2)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)

*Modulus of rupture = Equivalent fibre stress at maximum load.

MECHANICAL AND PHYSICAL PROPERTIES OF WOODS GROWN IN CANADA (GREEN CONDITION)

BENDING			IMPACT BENDING				COMPRESSION PARALLEL TO GRAIN				HARDNESS			SHEAR PARALLEL TO GRAIN		CLEAVAGE		TENSION PERPENDICULAR TO GRAIN	
Work in Bending in.-lb. per cu.in.											Load Required to Imbed 0.444-in. Sphere to Half Diameter. (lb.)			Maximum Stress (p.s.i.)		Splitting Strength (lb. per in. width; length 3 in.)		Maximum Stress (p.s.i.)	
To Proportional Limit	To Maximum Load	Total	Fibre Stress at Proportional Limit (p.s.i.)	Modulus of Elasticity (1,000 p.s.i.)	Work to Proportional Limit (inch-lb. per cu. in.)	Drop of 50-lb. Hammer at Complete Failure (in.)	Crushing Stress at Proportional Limit (p.s.i.)	Maximum Crushing Stress (p.s.i.)	Modulus of Elasticity (1,000 p.s.i.)	Compression Perpendicular to Grain. Stress at Proportional Limit (p.s.i.)	Radial Surface	Tangential Surface	End Surface	Radial Plane	Tangential Plane	Radial Plane	Tangential Plane	Radial Plane	Tangential Plane
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
0.47	8.6	13.1	6700	850	2.92	20	1230	1860	540	180	260	270	350	600	670	160	160	290	340
0.53	4.9	8.2	7600	1370	2.37	16	2310	2770	1170	280	250	300	430	670	720	140	140	230	250
0.58	8.1	21.6	10300	1700	3.51	31	2450	3190	1250	340	430	450	520	870	890	190	210	370	410
0.74	7.0	17.9	10200	1960	3.04	24	3150	3790	1810	530	500	520	610	910	930	210	210	360	370
0.70	6.9	13.8	7600	1490	2.20	17	2570	3180	1570	480	440	440	520	870	900	220	240	400	430
0.65	6.8	21.1	11500	2220	3.39	29	2720	3650	1630	440	440	440	570	930	940	210	230	360	440
0.37	5.5	11.9	8600	1600	2.66	19	2220	2760	1500	240	320	340	410	690	730	150	180	240	300
0.42	7.4	11.7	8000	1340	2.76	17	1690	2400	1210	240	270	290	320	630	700	140	160	270	320
0.62	7.7	21.8	9200	1520	3.11	24	2040	3270	1190	400	430	420	570	910	900	210	200	370	430
0.65	6.6	16.7	8900	1960	2.28	22	2990	3560	1620	380	450	470	560	710	790	190	210	360	420
0.45	10.5	36.0	8500	1290	3.18	34	1880	3060	1220	420	430	420	480	890	940	210	220	400	430
0.86	7.9	25.0	10600	2150	2.99	27	3450	4410	1880	520	580	590	640	900	940	240	250	400	430
0.62	6.8	25.4	8500	1500	2.77	28	2050	2950	1190	350	390	400	410	840	840	200	180	350	360
0.40	5.3	14.6	7600	1360	2.41	21	2220	2840	1430	280	350	370	340	710	740	190	190	310	350
0.44	5.8	25.1	8700	1400	3.10	27	1540	2260	1080	260	310	340	310	710	710	180	190	310	370
0.40	5.1	12.0	7600	1360	2.42	18	2030	2500	1280	230	270	280	290	640	670	140	150	200	250
0.56	5.4	19.9	8400	1730	2.29	23	2150	2840	1260	350	410	430	400	710	730	200	220	360	420
0.43	5.3	12.6	8100	1430	2.59	18	2040	2620	1280	240	290	290	320	620	650	160	170	290	350
0.42	8.1	24.0	8500	1530	2.69	25	1900	2820	1500	290	360	360	400	790	820	180	190	320	380
0.48	5.4	19.1	8300	1590	2.47	22	2180	2810	1280	270	330	350	340	690	710	180	190	290	340
0.40	8.3	18.4	8800	1670	2.60	23	1950	2800	1470	280	360	370	440	780	820	170	190	310	390
0.40	4.8	16.8	7000	1540	1.82	20	2050	2550	1510	280	320	330	400	610	660	150	180	280	340
0.38	5.8	15.0	7700	1290	2.61	22	1840	2470	1270	250	280	290	340	700	720	150	160	280	330
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
0.59	8.2	15.2	9000	1630	2.85	24	2340	3020	1190	360	430	440	540	860	960	210	270	380	520
0.39	20.1	51.7	10700	1250	5.47	62	1460	2470	1460	400	750	730	770	900	820	370	340	660	650
0.42	12.9	26.0	8100	1160	3.19	38	1140	2080	770	540	670	670	740	1000	970	330	310	670	660
0.65	23.3	60.9	11900	1780	4.90	71	2430	3820	1560	860	1100	1160	1160	1430	1470	510	500	970	1020
0.39	6.2	20.5	9000	1500	3.00	24	1140	2270	1190	200	320	340	390	660	780	150	190	370	530
0.68	13.4	39.0	14100	1940	6.20	54	2650	3820	1510	640	1030	990	1100	1190	1420	410	530	770	1040
0.40	13.8	45.7	9700	1950	2.76	42	1700	2770	1550	370	600	630	550	930	1000	280	320	560	660
0.49	11.9	41.6	11800	2240	3.53	39	2340	3250	1680	410	640	620	690	950	1090	280	340	550	680
0.60	20.3	53.2	12000	2050	4.03	53	2260	3400	1640	490	840	850	900	1120	1250	340	410	670	840
0.38	9.0	22.0	8800	1490	2.89	22	1230	2470	1160	240	410	420	460	650	720	200	230	450	530
0.52	12.9	36.3	12900	1730	5.44	44	1770	3330	1510	460	690	700	890	1050	1230	330	440	670	950
0.61	12.2	25.7	9400	1670	2.97	32	1960	3310	1290	340	600	620	710	1050	1070	280	300	690	660
0.69	19.6	50.9	12200	1610	5.17	75	1700	3450	1410	520	910	920	940	1080	1170	390	450	760	870
0.88	19.1	58.0	15200	1730	7.83	67	2740	4020	1510	760	1100	1100	1140	1350	1450	470	510	900	1020
0.61	15.4	40.3	10900	1300	5.38	62	1850	2960	1250	520	720	730	800	1040	1120	380	400	730	820
0.52	23.1	69.7	15200	2200	5.91	66	2250	4310	1910	790	1330	1370	1410	1380	1530	520	530	870	1130
0.68	22.4	71.2	14600	1870	6.37	88	2600	4390	1750	930	1410	1410	1490	1480	1620	510	560	980	1090
0.82	22.5	79.8	14500	2130	5.55	111	1930	3790	1580	700	1260	1270	1300	1350	1440	410	450	750	900
0.82	12.5	28.7	11600	2070	3.67	42	2860	3800	1350	560	710	710	830	1160	1370	350	440	650	920
0.54	9.7	23.1	8600	1440	2.93	33	1500	2350	940	330	510	530	560	830	970	240	250	450	490
0.67	11.6	30.5	11000	2360	2.92	35	2600	3650	1720	550	750	770	890	1150	1310	340	440	620	860
0.45	11.0	26.6	9900	1820	3.02	29	1990	2920	1540	380	600	580	710	900	1040	260	310	600	690
0.87	18.4	42.6	13600	2550	4.15	54	2880	4570	1840	890	1180	1170	1330	1490	1750	480	600	860	1220
0.71	17.1	50.3	14300	1830	6.34	67	2180	4190	1580	780	1050	1010	1230	1330	1410	470	510	870	970
0.56	20.2	46.6	10200	1130	5.39	79	1610	2670	950	750	970	960	1050	1300	1310	430	400	880	800
0.66	16.3	44.3	13600	2140	5.04	63	2370	3890	1520	780	1020	1010	1220	1340	1380	470	490	890	990
0.51	20.3	56.5	14600	1870	6.36	79	2140	3590	1700	710	1270	1230	1260	1190	1340	450	530	760	960
0.35	6.9	19.3	8200	1500	2.55	26	1480	2360	1280	200	340	350	370	730	780	180	220	390	510
0.40	8.8	24.4	8200	1390	2.72	33	1270	2370	1200	210	400	420	380	730	850	190	220	360	470
0.34	5.2	13.8	7300	1210	2.49	18	1300	2080	1260	170	260	300	290	620	680	150	170	290	340
0.45	9.2	28.3	7100	1110	2.63	38	1170	1980	920	210	410	440	430	730	810	190	250	400	580
0.71	17.6	45.2	15300	2270	5.90	69	2620	4050	1570	630	840	880	1100	1200	1370	440	510	780	960
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)

MECHANICAL AND PHYSICAL PROPERTIES OF WOODS GROWN IN CANADA (AIR-DRY CONDITION)

TABLE 1B

SPECIES	SPECIFIC GRAVITY Nominal: Volume Air-dry Weight Oven-dry	Weight Per Cubic Foot as Tested (lb.)	Moisture Content Based on Weight Oven-dry (Per Cent)	STATIC BENDING: Fibre Stress at Proportional Limit (p.s.i.)	Modulus of Rupture (p.s.i.)*	Modulus of Elasticity (1,000 p.s.i.)	Work in Bending inch-lb. per cu. in.: To Proportional Limit	To Maximum Load	Total	IMPACT: Fibre Stress at Proportional Limit (p.s.i.)	Modulus of Elasticity (1,000 p.s.i.)
(1)	(10)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Cedar, Eastern White	0.30	21	12	3600	6200	660	1.20	13.0	14.3	8300	890
Cedar, Western Red	0.33	23	11	5100	7900	1200	1.21	5.4	8.5	9600	1470
Cedar, Yellow	0.42	29	12	6600	11300	1560	1.59	12.1	15.8	12800	2090
Douglas Fir (Coast)	0.50	35	12	8600	13300	2050	2.03	10.9	22.5	16100	3610
Douglas Fir (Mountain)	0.46	32	10	9000	13800	1820	2.46	11.1	16.1	13000	2090
Douglas Fir (Second Growth)	0.45	31	12	7100	12200	1970	1.46	9.3	28.0	14700	2500
Fir, Amabilis	0.39	27	12	5700	9700	1690	1.10	8.4	17.9	12200	2170
Fir, Balsam	0.35	24	12	4600	8600	1380	0.90	8.7	14.5	10100	1760
Hemlock, Eastern	0.41	29	12	5800	9400	1220	1.57	8.5	12.8	10300	1890
Hemlock, Western	0.43	30	12	7300	11100	1690	1.78	9.3	17.6	10800	2170
Larch (Tamarack)	0.50	35	13	6600	9800	1210	2.06	7.5	17.3	10100	1770
Larch, Western	0.55	38	12	8700	13800	1960	2.15	10.9	20.0	14400	2710
Pine, Jack	0.44	31	13	6500	10800	1460	1.66	9.6	17.8	10800	1970
Pine, Lodgepole	0.41	29	13	6000	10000	1500	1.37	8.1	11.5	10400	1940
Pine, Red	0.40	28	12	5600	9700	1340	1.33	9.6	16.8	10900	1980
Pine, Western White	0.37	26	12	5500	9000	1450	1.17	8.6	12.2	12200	2170
Pine, Ponderosa	0.46	32	13	6400	10200	1400	1.65	8.7	10.9	11400	2350
Pine, White	0.38	26	10	6700	10400	1460	1.75	8.6	12.3	12100	1930
Spruce, Black	0.43	30	13	5700	10300	1520	1.23	9.2	15.6	10500	1880
Spruce, Engelmann	0.39	27	12	5900	10100	1560	1.29	8.8	16.4	11900	2420
Spruce, Red	0.40	28	13	5500	8900	1450	1.16	8.2	11.6	10000	2050
Spruce, Sitka	0.39	27	13	6600	10400	1720	1.44	9.9	22.3	10100	2080
Spruce, White	0.37	26	13	5200	8700	1390	1.16	7.8	15.2	9300	1690
(1)	(10)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Alder, Red	0.41	28	11	5900	10700	1450	1.35	9.6	13.3	12400	1990
Ash, Black	0.49	35	14	5100	10900	1660	0.94	13.8	36.0	14300	1820
Ash, Green	0.49	35	13	3900	8200	770	1.15	12.3			
Ash, White	0.63	44	12	7500	15100	1700	1.89	23.0	51.3	18000	2320
Basswood	0.42	29	12	4500	8700	1400	0.81	9.5	15.1	11300	2220
Beech	0.66	46	12	8600	16100	1990	2.10	19.5	36.7	17600	2850
Birch, White	0.58	40	12	7900	14000	1880	1.89	20.2	40.6	13200	2520
Birch, Western White	0.56	39	12	8000	14500	2140	1.69	18.3	38.3	16700	2960
Birch, Yellow	0.62	43	13	8700	15800	2140	1.99	21.7	49.5	17900	2960
Butternut	0.39	27	11	3600	8500	1380	0.55	7.9	14.5	9600	1870
Cherry, Black	0.55	37	9	9900	14200	1820	3.04	10.0	20.5	15600	2240
Chestnut	0.45	31	11	7700	11200	1410	2.35	7.6	17.2	10500	1760
Elm, Slippery	0.60	42	13	4500	11600	1510	0.72	20.1	65.1	17700	2380
Elm, Rock	0.69	49	13	8100	16300	1950	1.90	27.3	62.0	19300	2770
Elm, White	0.56	39	13	6000	12000	1520	1.33	19.3	45.3	16400	2370
Hickory, Bitternut	0.68	49	15	8000	16500	2350	1.55	22.8	57.6	19400	2890
Hickory, Shagbark	0.71	50	12	9000	16600	1980	2.31	22.6	75.2	17900	2940
Ironwood	0.72	50	11	10000	19400	2250	2.48	26.8	80.1	19500	3030
Maple, Broadleaf	0.51	36	12	6000	13200	1660	1.22	15.5	25.3	13100	2200
Maple, Manitoba	0.45	31	12								
Maple, Red	0.54	38	13	6800	12800	1680	1.59	15.0	21.5		
Maple, Silver	0.48	34	14	4700	11100	1660	0.75	12.1	17.9	12500	2230
Maple, Sugar	0.66	47	14	8700	16100	2120	2.04	19.5	44.0	16500	3350
Oak, Black	0.63	45	14	7600	12900	1630	1.97	17.9	40.8	17000	2450
Oak, Bur	0.65	46	14	6100	12100	1110	1.85	18.1	47.3		
Oak, Red	0.61	43	12	8300	13800	1690	2.28	15.9	38.0	18000	2430
Oak, White	0.68	49	15	4800	14300	2010	0.66	21.7	52.5	21800	2830
Poplar, Aspen	0.40	28	11	5400	9900	1610	1.05	10.8	21.7	10500	1830
Poplar (Largetooth Aspen)	0.40	28	13	4400	9100	1310	0.83	9.7	20.7		
Poplar, Balsam	0.41	29	12	4800	9600	1620	0.86	10.5	25.8		
Poplar (Cottonwood)	0.39	27	12	5000	9300	1330	1.12	10.9	23.4	9500	1630
Walnut, Black	0.59	41	12	9100	15000	1900	2.47	16.8	30.7	17600	2490
(1)	(10)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)

*Modulus of rupture = Equivalent fibre stress at maximum load.

MECHANICAL AND PHYSICAL PROPERTIES OF WOODS GROWN IN CANADA (AIR-DRY CONDITION)

BENDING: Work to Proportional Limit (inch-lb. per cu. in.)	BENDING: Drop of 50-lb. Hammer at Complete Failure (in.)	COMPRESSION PARALLEL TO GRAIN: Crushing Stress at Proportional Limit (p.s.i.)	COMPRESSION PARALLEL TO GRAIN: Maximum Crushing Stress (p.s.i.)	COMPRESSION PARALLEL TO GRAIN: Modulus of Elasticity (1,000 p.s.i.)	Compression Perpendicular to Grain. Stress at Proportional Limit (p.s.i.)	HARDNESS — Load Required to Imbed 0.444-in. Sphere to Half Diameter. (lb.): Radial Surface	HARDNESS: Tangential Surface	HARDNESS: End Surface	SHEAR PARALLEL TO GRAIN — Maximum Stress (p.s.i.): Radial Plane	SHEAR PARALLEL TO GRAIN: Tangential Plane	CLEAVAGE — Splitting Strength (lb. per in. width; length 3 in.): Radial Plane	CLEAVAGE: Tangential Plane	TENSION PERPENDICULAR TO GRAIN — Maximum Stress (p.s.i.): Radial Plane	TENSION PERPENDICULAR TO GRAIN: Tangential Plane
(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
4.31	21	2270	3530	710	410	280	310	500	890	950	180	180	320	360
3.55	17	3960	4980	1290	530	330	360	700	830	850	130	160	180	210
4.45	30	4460	6520	1430	660	540	560	880	1330	1360	260	270	490	510
4.08	40	5500	7700	2010	980	730	740	940	1480	1440	220	260	390	450
4.48	30	4000	7470	1860	1010	670	690	790	1260	1180	240	290	460	460
4.87	35	5050	6790	1890	740	660	670	990	1490	1310	180	190	270	290
3.85	27	4180	5870	1750	480	390	450	800	1080	1020	190	190	340	390
3.25	20	3280	5070	1420	460	370	430	710	890	980	150	170	280	370
3.17	22	3540	5680	1460	630	530	540	900	1290	1170	180	190	290	360
3.02	26	5150	6390	1720	650	550	610	940	940	960	190	210	400	420
3.29	15	3610	6190	1430	970	690	710	870	1260	1250	240	250	470	550
4.50	30	5860	8640	1930	1020	840	850	1090	1460	1320	260	260	500	500
3.28	25	3300	5700	1480	790	530	600	690	1180	1150	250	240	510	540
3.21	21	4070	5710	1590	510	460	470	630	1250	1230	280	280	510	530
3.39	26	3370	5320	1320	690	430	490	560	1090	1080	210	250	460	540
3.86	24	4010	5200	1450	450	360	390	490	940	920	190	210	350	420
3.20	22	3940	6050	1480	780	520	560	710	980	1010	250	300	430	500
4.26	20	4100	5780	1520	580	390	420	540	880	890	190	220	370	470
3.24	26	4030	5850	1780	620	500	550	680	1190	1250	260	280	460	510
3.30	23	4610	6120	1730	520	440	490	600	1140	1130	240	250	400	420
2.75	22	3110	5300	1730	500	430	490	660	1220	1250	270	280	490	570
2.80	26	3380	5500	1740	650	510	560	750	1050	970	200	240	490	330
2.84	22	3420	5000	1580	480	390	440	540	1020	1010	230	230	450	470
(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
4.31	29	3930	5790	1320	580	540	580	980	1080	1230	280	330	390	440
6.25	55	2750	5140	1900	740	960	950	1110	1490	1380	450	360	750	800
		2180	4300	1110	1130	850	780	1260	1580	1490	410	330	890	830
7.89	57	3570	7430	1840	1520	1610	1650	2030	2340	2320	500	540	1140	1170
3.21	27	2090	4920	1710	370	510	480	580	1030	1240	230	290	550	780
6.23	61	4400	7870	2040	1200	1420	1450	1790	1980	2300	500	640	1110	1480
3.87	49	3780	6710	2050	980	990	1020	970	1700	1810	470	540	1080	1150
5.32	60	4650	7320	1960	820	990	960	1060	1730	1960	420	530	590	720
6.24	63	4790	7730	2290	990	1280	1270	1500	1870	2140	540	630	980	1160
2.73	21	2280	5210	1500	480	590	600	790	1100	1180	290	320	570	660
6.09	42	5470	8620	1850	1240	1090	1160	1750	1670	1890	370	510	800	1030
3.54	23	4230	6230	1470	790	650	680	1030	1310	1410	240	290	520	590
7.34	92	2470	5550	1680	940	1520	1370	1570	1810	1880	600	540	960	1160
7.70	85	4430	7230	2000	1320	1560	1640	1710	2010	2140	550	600	1010	1260
6.54	62	2930	5440	1570	880	1030	1020	1230	1590	1630	440	450	880	900
7.34	95	3360	7530	2510	1550	1830	1790	1950	2180	2330	740	700	1360	1390
6.14	72	4620	8200	2280	1850	2060	2040	2240	2560	2690	670	720	1290	1320
6.99	93	4540	8690	2080	1610	2000	1870	2190	2250	2570	600	650	1110	1120
4.36	41	3890	6140	1430	830	890	950	1300	1620	1910	450	540	640	930
		3050	4800	1230	680	670	730	1010	1300	1390	270	360	590	730
		3510	6350	1900	990	860	1020	1300	1420	1590	390	430	850	930
3.92	30	3270	5430	1780	630	750	790	1120	1400	1550	380	440	750	1010
4.52	55	4380	7730	2180	1350	1640	1670	1970	2120	2540	510	740	1080	1500
6.64	63	3380	6510	1960	1260	1420	1390	1540	1880	2000	450	550	990	1210
		2450	5620	1270	1290	1240	1220	1530	1730	1830	390	530	780	1100
7.43	56	3800	7040	1910	1270	1320	1320	1600	2060	2110	470	490	850	1040
9.34	71	2670	6450	2140	1120	1370	1400	1620	1830	1910	560	600	1050	1180
3.37	26	3470	5310	1810	480	470	490	630	880	1090	250	290	540	690
		2570	4270	1500	560	400	490	550	950	1320	250	280	590	720
		2980	5060	1790	440	410	450	630	850	1000	220	240	500	470
3.12	25	2630	4730	1540	490	430	470	690	1120	1300	260	310	620	750
6.95	55	4450	7780	1890	1240	1300	1310	1620	2000	2250	510	570	960	1230
(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)

TABLE
2

(a) RECOMMENDED SAFE WORKING STRESSES FOR CANADIAN TIMBERS

SPECIES	BENDING (pounds per square inch)			COMPRESSION (pounds per square inch)	
	STRESS AT EXTREME FIBRE	MODULUS OF ELASTICITY	LONGITUDINAL SHEAR	PERPENDICULAR TO GRAIN	PARALLEL TO GRAIN (SHORT COLUMNS)
SELECT STRUCTURAL GRADE*					
Cedar, Eastern	800	800,000	75	130	600
Cedar, Western	1000	1,000,000	90	145	800
Douglas Fir, Coast	1700	1,600,000	100	235	1200
Douglas Fir, Coast (dense)	1900	1,600,000	115	280	1400
Douglas Fir, Mountain	1400	1,400,000	85	220	1000
Fir, Amabilis	1000	1,100,000	75	160	800
Hemlock, Eastern	1200	1,100,000	75	220	800
Hemlock, Western	1400	1,400,000	90	220	1000
Larch (Tamarack)	1300	1,300,000	105	220	1000
Larch, Western	1700	1,500,000	100	235	1200
Pine, Jack	1200	1,100,000	90	200	800
Pine, Lodgepole	1000	1,000,000	70	160	800
Pine, Red	1200	1,200,000	90	185	800
Pine, Ponderosa, Eastern and Western White	1000	1,000,000	90	185	800
Spruce, Eastern, Engelmann and Sitka	1200	1,200,000	90	185	800
Beech	1700	1,600,000	140	365	1300
Birch, Yellow	1700	1,600,000	140	365	1300
Elm, White	1200	1,200,000	115	185	900
Maple, Sugar	1700	1,600,000	140	365	1300
Oak, Red and White	1500	1,500,000	140	365	1100
STRUCTURAL GRADE*					
Cedar, Eastern	660	800,000	60	130	480
Cedar, Western	780	1,000,000	72	145	640
Douglas Fir, Coast	1320	1,600,000	78	235	960
Douglas Fir, Coast (dense)	1530	1,600,000	90	280	1120
Douglas Fir, Mountain	1140	1,400,000	66	220	800
Fir, Amabilis	780	1,100,000	60	160	640
Hemlock, Eastern	960	1,100,000	60	220	640
Hemlock, Western	1140	1,400,000	72	220	800
Larch (Tamarack)	1050	1,300,000	84	220	800
Larch, Western	1320	1,500,000	78	235	960
Pine, Jack	960	1,100,000	72	200	640
Pine, Lodgepole	780	1,000,000	54	160	640
Pine, Red	960	1,200,000	72	185	640
Pine, Ponderosa, Eastern and Western White	780	1,000,000	72	185	640
Spruce, Eastern, Engelmann and Sitka	960	1,200,000	72	185	640
Beech	1320	1,600,000	110	365	1040
Birch, Yellow	1320	1,600,000	110	365	1040
Elm, White	960	1,200,000	90	185	720
Maple, Sugar	1320	1,600,000	110	365	1040
Oak, Red and White	1230	1,500,000	110	365	880

*The stresses in the above table are recommended for timbers which have been graded for defects in accordance with the Canadian Standards Association grading rules for structural timber.

(b) PERCENTAGE OF THE ABOVE STRESS VALUES APPLICABLE WHEN STRUCTURAL TIMBERS ARE USED UNDER THE FOLLOWING CONDITIONS OF MOISTURE CONTENT AND DECAY HAZARD

KIND OF STRESS	CONTINUOUSLY DRY	CONTINUOUSLY SUBMERGED	OCCASIONALLY WET AND QUICKLY DRIED	MORE OR LESS CONTINUALLY WET OR DAMP
Extreme fibre in bending	100	100	85	70
Compression perpendicular	150	100	100	85
Compression parallel	100	100	90	80
Longitudinal shear	100	100	100	100
Modulus of elasticity	100	100	100	100

RECOMMENDED SAFE WORKING STRESSES FOR TIMBER COLUMNS

TABLE 3

SPECIES	COMPRESSION PARALLEL TO GRAIN (pounds per square inch) RATIO OF LENGTH TO LEAST DIMENSION L/D															MODULUS OF ELASTICITY (pounds per square inch)
	10	12	14	16	18	20	22	24	26	28	30	35	40	45	50	
SELECT STRUCTURAL GRADE*																
Cedar, Eastern	600	590	570	560	530	490	440	380	330	280	240	180	140	110	90	800,000
Cedar, Western	800	780	760	730	690	640	560	480	410	350	310	220	170	140	110	1,000,000
Douglas Fir, Coast	1200	1170	1150	1110	1060	990	890	760	650	560	490	360	270	220	180	1,600,000
Douglas Fir, Coast (dense)	1400	1360	1320	1260	1170	1060	910	760	650	560	490	360	270	220	180	1,600,000
Douglas Fir, Mountain	1000	980	960	930	890	840	760	670	570	490	430	310	240	190	150	1,400,000
Fir, Amabilis	800	780	770	750	710	670	610	520	450	390	340	250	190	150	120	1,100,000
Hemlock, Eastern	800	780	770	750	710	670	610	520	450	390	340	250	190	150	120	1,100,000
Hemlock, Western	1000	980	960	930	890	840	760	670	570	490	430	310	240	190	150	1,400,000
Larch, (Tamarack)	1000	980	960	920	880	810	720	620	530	460	400	290	220	180	140	1,300,000
Larch, Western	1200	1170	1140	1100	1040	950	840	710	610	520	460	340	260	200	160	1,500,000
Pine, Jack	800	780	770	750	710	670	610	520	450	390	340	250	190	150	120	1,100,000
Pine, Lodgepole	800	780	760	730	690	640	560	480	410	350	310	220	170	140	110	1,000,000
Pine, Red	800	790	770	750	730	690	630	570	490	420	370	270	210	160	130	1,200,000
Pine, Western White	800	780	760	730	690	640	560	480	410	350	310	220	170	140	110	1,000,000
Pine, Ponderosa	800	780	760	730	690	640	560	480	410	350	310	220	170	140	110	1,000,000
Pine, White	800	780	760	730	690	640	560	480	410	350	310	220	170	140	110	1,000,000
Spruce, Eastern	800	790	770	750	730	690	630	570	490	420	370	270	210	160	130	1,200,000
Spruce, Sitka	800	790	770	750	730	690	630	570	490	420	370	270	210	160	130	1,200,000
Spruce, Engelmann	800	790	770	750	730	690	630	570	490	420	370	270	210	160	130	1,200,000
Beech	1300	1260	1240	1190	1120	1030	900	760	650	560	490	360	270	220	180	1,600,000
Birch, Yellow	1300	1260	1240	1190	1120	1030	900	760	650	560	490	360	270	220	180	1,600,000
Elm, White	900	880	860	830	790	740	670	570	490	420	370	270	210	160	130	1,200,000
Maple, Hard	1300	1260	1240	1190	1120	1030	900	760	650	560	490	360	270	220	180	1,600,000
Oak, Red and White	1100	1080	1050	1020	980	910	820	710	610	520	460	340	260	200	160	1,500,000
STRUCTURAL GRADE*																
Cedar, Eastern	480	470	470	460	440	430	400	370	320	280	240	180	140	110	90	800,000
Cedar, Western	640	630	620	610	590	560	520	470	410	350	300	220	170	140	110	1,000,000
Douglas Fir, Coast	960	950	930	920	890	850	800	730	650	560	490	360	270	220	180	1,600,000
Douglas Fir, Coast (dense)	1120	1100	1080	1050	1010	950	870	760	650	560	490	360	270	220	180	1,600,000
Douglas Fir, Mountain	800	790	780	770	750	720	680	630	560	490	430	310	240	190	150	1,400,000
Fir, Amabilis	640	630	620	610	600	570	540	500	440	380	340	250	190	150	120	1,100,000
Hemlock, Eastern	640	630	620	610	600	570	540	500	440	380	340	250	190	150	120	1,100,000
Hemlock, Western	800	790	780	770	750	720	680	630	560	490	430	310	240	190	150	1,400,000
Larch, (Tamarack)	800	790	780	760	740	700	660	600	530	450	400	290	220	180	140	1,300,000
Larch, Western	960	940	930	910	880	840	780	700	610	520	460	340	260	200	160	1,500,000
Pine, Jack	640	630	620	610	600	570	540	500	440	380	340	250	190	150	120	1,100,000
Pine, Lodgepole	640	630	620	610	590	560	520	470	410	350	300	220	170	140	110	1,000,000
Pine, Red	640	630	630	620	600	580	560	520	480	420	370	270	210	160	130	1,200,000
Pine, Western White	640	630	620	610	590	560	520	470	410	350	300	220	170	140	110	1,000,000
Pine, Ponderosa	640	630	620	610	590	560	520	470	410	350	300	220	170	140	110	1,000,000
Pine, White	640	630	620	610	590	560	520	470	410	350	300	220	170	140	110	1,000,000
Spruce, Eastern	640	630	630	620	600	580	560	520	480	420	370	270	210	160	130	1,200,000
Spruce, Sitka	640	630	630	620	600	580	560	520	480	420	370	270	210	160	130	1,200,000
Spruce, Engelmann	640	630	630	620	600	580	560	520	480	420	370	270	210	160	130	1,200,000
Beech	1040	1020	1010	980	950	900	840	750	650	560	490	360	270	220	180	1,600,000
Birch, Yellow	1040	1020	1010	980	950	900	840	750	650	560	490	360	270	220	180	1,600,000
Elm, White	720	710	700	690	670	640	600	550	480	420	370	270	210	160	130	1,200,000
Maple, Hard	1040	1020	1010	980	950	900	840	750	650	560	490	360	270	220	180	1,600,000
Oak, Red and White	880	870	860	840	820	780	740	680	600	520	460	340	260	200	160	1,500,000

*The stresses in the above table are recommended for timbers which have been graded for defects in accordance with the Canadian Standards Association grading rules for structural timber.

MAXIMUM MOMENTS OF RESISTANCE (Foot Pounds) FOR JOISTS AND BEAMS (Full Sizes)

TABLE
4

SIZE IN INCHES	SAFE ALLOWABLE WORKING STRESS IN BENDING IN POUNDS PER SQUARE INCH*														
	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
2 × 2	70	80	90	100	110	120	130	140	160	170	180	190	200	210	220
3	150	180	200	230	250	280	300	330	350	380	400	430	450	480	500
4	270	310	360	400	440	490	530	580	620	670	710	760	800	840	890
6	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000
8	1,070	1,240	1,420	1,600	1,780	1,960	2,130	2,310	2,490	2,670	2,840	3,020	3,200	3,380	3,560
10	1,670	1,940	2,220	2,500	2,780	3,060	3,330	3,610	3,890	4,170	4,440	4,720	5,000	5,280	5,560
12	2,400	2,800	3,200	3,600	4,000	4,400	4,800	5,200	5,600	6,000	6,400	6,800	7,200	7,600	8,000
14	3,270	3,810	4,360	4,900	5,440	5,990	6,530	7,080	7,620	8,170	8,710	9,260	9,800	10,340	10,890
16	4,270	4,980	5,690	6,400	7,110	7,820	8,530	9,240	9,960	10,670	11,380	12,090	12,800	13,510	14,220
3 × 3	230	260	300	340	380	410	450	490	530	560	600	640	680	710	750
4	400	470	530	600	670	730	800	870	930	1,000	1,070	1,130	1,200	1,270	1,330
6	900	1,050	1,200	1,350	1,500	1,650	1,800	1,950	2,100	2,250	2,400	2,550	2,700	2,850	3,000
8	1,600	1,870	2,130	2,400	2,670	2,930	3,200	3,470	3,730	4,000	4,270	4,530	4,800	5,070	5,330
10	2,500	2,920	3,330	3,750	4,170	4,580	5,000	5,420	5,830	6,250	6,670	7,080	7,500	7,920	8,330
12	3,600	4,200	4,800	5,400	6,000	6,600	7,200	7,800	8,400	9,000	9,600	10,200	10,800	11,400	12,000
14	4,900	5,720	6,530	7,350	8,170	8,980	9,800	10,620	11,430	12,250	13,070	13,880	14,700	15,520	16,330
16	6,400	7,470	8,530	9,600	10,670	11,730	12,800	13,870	14,930	16,000	17,070	18,130	19,200	20,270	21,330
18	8,100	9,450	10,800	12,150	13,500	14,850	16,200	17,550	18,900	20,250	21,600	22,950	24,300	25,650	27,000
4 × 4	530	620	710	800	890	980	1,070	1,160	1,240	1,330	1,420	1,510	1,600	1,690	1,780
6	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200	3,400	3,600	3,800	4,000
8	2,130	2,490	2,840	3,200	3,560	3,910	4,270	4,620	4,980	5,330	5,690	6,040	6,400	6,760	7,110
10	3,330	3,890	4,440	5,000	5,560	6,110	6,670	7,220	7,780	8,330	8,890	9,440	10,000	10,560	11,110
12	4,800	5,600	6,400	7,200	8,000	8,800	9,600	10,400	11,200	12,000	12,800	13,600	14,400	15,200	16,000
14	6,530	7,620	8,710	9,800	10,890	11,980	13,070	14,160	15,240	16,330	17,420	18,510	19,600	20,690	21,780
16	8,530	9,960	11,380	12,800	14,220	15,640	17,070	18,490	19,910	21,330	22,760	24,180	25,600	27,020	28,440
18	10,800	12,600	14,400	16,200	18,000	19,800	21,600	23,400	25,200	27,000	28,800	30,600	32,400	34,200	36,000
20	13,330	15,560	17,780	20,000	22,220	24,440	26,670	28,890	31,110	33,330	35,560	37,780	40,000	42,220	44,440
6 × 6	1,800	2,100	2,400	2,700	3,000	3,300	3,600	3,900	4,200	4,500	4,800	5,100	5,400	5,700	6,000
8	3,200	3,730	4,270	4,800	5,330	5,870	6,400	6,930	7,470	8,000	8,530	9,070	9,600	10,130	10,670
10	5,000	5,830	6,670	7,500	8,330	9,170	10,000	10,830	11,670	12,500	13,330	14,170	15,000	15,830	16,670
12	7,200	8,400	9,600	10,800	12,000	13,200	14,400	15,600	16,800	18,000	19,200	20,400	21,600	22,800	24,000
14	9,800	11,430	13,070	14,700	16,330	17,970	19,600	21,230	22,870	24,500	26,130	27,770	29,400	31,030	32,670
16	12,800	14,930	17,070	19,200	21,330	23,470	25,600	27,730	29,870	32,000	34,130	36,270	38,400	40,530	42,670
18	16,200	18,900	21,600	24,300	27,000	29,700	32,400	35,100	37,800	40,500	43,200	45,900	48,600	51,300	54,000
20	20,000	23,330	26,670	30,000	33,330	36,670	40,000	43,330	46,670	50,000	53,330	56,670	60,000	63,330	66,670
8 × 8	4,270	4,980	5,690	6,400	7,110	7,820	8,530	9,240	9,960	10,670	11,380	12,090	12,800	13,510	14,220
10	6,670	7,780	8,890	10,000	11,110	12,220	13,330	14,440	15,560	16,670	17,780	18,890	20,000	21,110	22,220
12	9,600	11,200	12,800	14,400	16,000	17,600	19,200	20,800	22,400	24,000	25,600	27,200	28,800	30,400	32,000
14	13,070	15,240	17,420	19,600	21,780	23,960	26,130	28,310	30,490	32,670	34,840	37,020	39,200	41,380	43,560
16	17,070	19,910	22,760	25,600	28,440	31,290	34,130	36,980	39,820	42,670	45,510	48,360	51,200	54,040	56,890
18	21,600	25,200	28,800	32,400	36,000	39,600	43,200	46,800	50,400	54,000	57,600	61,200	64,800	68,400	72,000
20	26,670	31,110	35,560	40,000	44,440	48,890	53,330	57,780	62,220	66,670	71,110	75,560	80,000	84,440	88,890
10 × 10	8,330	9,720	11,110	12,500	13,890	15,280	16,670	18,060	19,440	20,830	22,220	23,610	25,000	26,390	27,780
12	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000
14	16,330	19,060	21,780	24,500	27,220	29,940	32,670	35,390	38,110	40,830	43,560	46,280	49,000	51,720	54,440
16	21,330	24,890	28,440	32,000	35,560	39,110	42,670	46,220	49,780	53,330	56,890	60,440	64,000	67,560	71,110
18	27,000	31,500	36,000	40,500	45,000	49,500	54,000	58,500	63,000	67,500	72,000	76,500	81,000	85,500	90,000
20	33,330	38,890	44,440	50,000	55,560	61,110	66,670	72,220	77,780	83,330	88,890	94,440	100,000	115,560	111,110
12 × 12	14,400	16,800	19,200	21,600	24,000	26,400	28,800	31,200	33,600	36,000	38,400	40,800	43,200	45,600	48,000
14	19,600	22,870	26,130	29,400	32,670	35,930	39,200	42,470	45,730	49,000	52,270	55,530	58,800	62,070	65,330
16	25,600	29,870	34,130	38,400	42,670	46,930	51,200	55,470	59,730	64,000	68,270	72,530	76,800	81,070	85,330
18	32,400	37,800	43,200	48,600	54,000	59,400	64,800	70,200	75,600	81,000	86,400	91,800	97,200	102,600	108,000
20	40,000	46,670	53,330	60,000	66,670	73,330	80,000	86,670	93,330	100,000	106,670	113,330	120,000	126,670	133,330
14 × 14	22,870	26,680	30,490	34,300	38,110	41,920	45,730	49,540	53,360	57,170	60,980	64,790	68,600	72,410	76,220
16	29,870	34,840	39,820	44,800	49,780	54,760	59,730	64,710	69,690	74,670	79,640	84,620	89,600	94,580	99,560
18	37,800	44,100	50,400	56,700	63,000	69,300	75,600	81,900	88,200	94,500	100,800	107,100	113,400	119,700	126,000
20	46,670	54,440	62,220	70,000	77,780	85,560	93,330	101,000	108,890	116,670	124,440	132,220	140,000	147,780	155,560
16 × 16	34,130	39,820	45,510	51,200	56,890	62,580	68,270	73,960	79,640	85,330	91,020	96,710	102,400	108,090	113,780
18	43,200	50,400	57,600	64,800	72,000	79,200	86,400	93,600	100,800	108,000	115,200	122,400	129,600	136,800	144,000
20	53,330	62,220	71,110	80,000	88,890	97,780	106,670	115,560	124,440	133,330	142,220	151,110	160,000	168,890	177,780
18 × 18	48,600	56,700	64,800	72,900	81,000	89,100	97,200	105,300	113,400	121,500	129,600	137,700	145,800	153,900	162,000
20	60,000	70,000	80,000	90,000	100,000	110,000	120,000	130,000	140,000	150,000	160,000	170,000	180,000	190,000	200,000
20 × 20	66,670	77,780	88,890	100,000	111,110	122,220	133,330	144,440	155,560	166,670	177,780	188,890	200,000	211,110	222,220

*For species corresponding to these working stresses, see Table 2, Column headed "Stress at Extreme Fibre".

MAXIMUM MOMENTS OF RESISTANCE (Foot Pounds) FOR JOISTS AND BEAMS (Dressed Sizes)

TABLE 5

SIZE IN INCHES	SAFE ALLOWABLE WORKING STRESS IN BENDING IN POUNDS PER SQUARE INCH*														
	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
1⅝ × 1⅝	40	40	50	50	60	70	70	80	80	90	100	100	110	110	120
2⅝	90	110	130	140	160	170	190	200	220	230	250	270	280	300	310
3⅝	180	210	240	270	300	330	360	390	420	450	480	510	540	560	590
5⅝	430	500	570	640	710	790	860	930	1,000	1,070	1,140	1,210	1,290	1,360	1,430
7½	760	890	1,020	1,140	1,270	1,400	1,520	1,650	1,780	1,900	2,030	2,160	2,280	2,410	2,540
9½	1,220	1,430	1,630	1,830	2,040	2,240	2,440	2,650	2,850	3,060	3,260	3,460	3,670	3,870	4,070
11½	1,790	2,090	2,390	2,690	2,990	3,280	3,580	3,880	4,180	4,480	4,780	5,080	5,370	5,670	5,970
13½	2,470	2,880	3,290	3,700	4,110	4,520	4,940	5,350	5,760	6,170	6,580	6,990	7,400	7,820	8,230
15½	3,250	3,800	4,340	4,880	5,420	5,960	6,510	7,050	7,590	8,130	8,680	9,220	9,760	10,300	10,840
2⅝ × 2⅝	150	180	200	230	250	280	300	330	350	380	400	430	450	480	500
3⅝	290	340	380	430	480	530	580	620	670	720	770	810	860	910	960
5⅝	690	810	920	1,040	1,150	1,270	1,380	1,500	1,610	1,730	1,850	1,960	2,080	2,190	2,310
7½	1,230	1,440	1,640	1,850	2,050	2,260	2,460	2,670	2,870	3,080	3,280	3,490	3,690	3,900	4,100
9½	1,970	2,300	2,630	2,960	3,290	3,620	3,950	4,280	4,610	4,940	5,260	5,590	5,920	6,250	6,580
11½	2,890	3,380	3,860	4,340	4,820	5,300	5,790	6,270	6,750	7,230	7,720	8,200	8,680	9,160	9,640
13½	3,990	4,650	5,320	5,980	6,640	7,310	7,970	8,640	9,300	9,970	10,630	11,300	11,960	12,620	13,290
15½	5,260	6,130	7,010	7,880	8,760	9,640	10,510	11,390	12,260	13,140	14,010	14,890	15,770	16,640	17,520
17½	6,700	7,820	8,930	10,050	11,170	12,280	13,400	14,520	15,630	16,750	17,860	18,980	20,100	21,210	22,330
3⅝ × 3⅝	400	460	530	600	660	730	790	860	930	990	1,060	1,130	1,190	1,260	1,320
5⅝	960	1,120	1,270	1,430	1,590	1,750	1,910	2,070	2,230	2,390	2,550	2,710	2,870	3,030	3,190
7½	1,700	1,980	2,270	2,550	2,830	3,120	3,400	3,680	3,970	4,250	4,530	4,810	5,100	5,380	5,660
9½	2,730	3,180	3,640	4,090	4,540	5,000	5,450	5,190	6,360	6,820	7,270	7,730	8,180	8,630	9,090
11½	4,000	4,660	5,330	5,990	6,660	7,320	7,990	8,660	9,320	9,990	10,650	11,320	11,980	12,650	13,320
13½	5,510	6,420	7,340	8,260	9,180	10,090	11,010	11,930	12,850	13,760	14,680	15,600	16,520	17,430	18,350
15½	7,260	8,470	9,680	10,890	12,100	13,310	14,520	15,730	16,930	18,140	19,350	20,560	21,770	22,980	24,190
17½	9,250	10,790	12,340	13,880	15,420	16,960	18,500	20,050	21,590	23,130	24,670	26,210	27,750	29,300	30,840
19½	11,490	13,400	15,320	17,230	19,140	21,060	22,970	24,890	26,800	28,720	30,630	32,550	34,460	36,370	38,290
5½ × 5½	1,390	1,620	1,850	2,080	2,310	2,540	2,770	3,000	3,240	3,470	3,700	3,930	4,160	4,390	4,620
7½	2,580	3,010	3,440	3,870	4,300	4,730	5,160	5,590	6,020	6,450	6,880	7,310	7,740	8,160	8,590
9½	4,140	4,830	5,520	6,210	6,890	7,580	8,270	8,960	9,650	10,340	11,030	11,720	12,410	13,100	13,790
11½	6,060	7,070	8,080	9,090	10,100	11,110	12,120	13,130	14,140	15,150	16,160	17,170	18,180	19,190	20,200
13½	8,350	9,750	11,140	12,530	13,920	15,310	16,710	18,100	19,490	20,880	22,280	23,670	25,060	26,450	27,840
15½	11,010	12,850	14,680	16,520	18,350	20,190	22,020	23,860	25,690	27,530	29,370	31,200	33,040	34,870	36,710
17½	14,040	16,380	18,720	21,060	23,400	25,740	28,070	30,410	32,750	35,090	37,430	38,770	42,110	44,450	46,790
19½	17,340	20,330	23,240	26,140	29,050	31,950	34,860	37,760	40,670	43,570	46,480	49,380	52,290	55,190	58,100
7½ × 7½	3,520	4,100	4,690	5,270	5,860	6,450	7,030	7,620	8,200	8,790	9,370	9,960	10,550	11,130	11,720
9½	5,640	6,580	7,520	8,460	9,400	10,340	11,280	12,220	13,160	14,100	15,040	15,980	16,920	17,860	18,800
11½	8,270	9,640	11,020	12,400	13,780	15,150	16,530	17,910	19,290	20,660	22,040	23,420	24,800	26,170	27,660
13½	11,390	13,290	15,190	17,090	18,980	20,880	22,780	24,680	26,580	28,480	30,370	32,270	34,170	36,070	37,970
15½	15,020	17,520	20,020	22,520	25,030	27,530	30,030	32,530	35,040	37,540	40,040	42,540	45,050	47,550	50,050
17½	19,140	22,330	25,520	28,710	31,900	35,090	38,280	41,470	44,660	47,850	51,040	54,230	57,420	60,610	63,800
19½	23,770	27,730	31,690	35,650	39,610	43,570	47,530	51,490	55,450	59,410	63,370	67,340	71,300	75,260	79,220
9½ × 9½	7,140	8,340	9,530	10,720	11,910	13,000	14,290	15,480	16,670	17,860	19,050	20,240	21,430	22,620	23,810
11½	10,470	12,210	13,960	15,700	17,450	19,190	20,940	22,680	24,430	26,170	27,920	29,660	31,410	33,150	34,900
13½	14,430	16,830	19,240	21,640	24,050	26,450	28,860	31,260	33,670	36,070	38,480	40,880	43,290	45,690	48,090
15½	19,020	22,190	25,360	28,530	31,800	34,870	38,040	41,210	44,380	47,550	50,720	53,890	57,060	60,230	63,400
17½	24,240	28,290	32,330	36,370	40,410	44,450	48,490	52,530	56,570	60,610	64,650	68,690	72,730	76,770	80,810
19½	30,100	35,120	40,140	45,150	50,170	55,190	60,210	65,220	70,240	75,260	80,270	85,290	90,310	95,330	100,340
11½ × 11½	12,670	14,790	16,900	19,010	21,120	23,240	25,350	27,460	29,570	31,690	33,800	35,910	38,020	40,130	42,250
13½	17,470	20,370	23,290	26,200	29,110	32,020	34,930	37,840	40,750	43,670	46,580	49,490	52,400	55,310	58,220
15½	23,020	26,860	30,700	34,540	38,370	42,210	46,050	49,890	53,720	57,560	61,400	65,240	69,070	72,910	76,750
17½	29,350	34,240	39,130	44,020	48,920	53,810	58,700	63,590	68,480	73,370	78,270	83,160	88,050	92,940	97,830
19½	36,440	42,520	48,590	54,660	60,740	66,180	72,880	78,960	85,030	91,100	97,180	103,250	109,330	115,400	121,470
13½ × 13½	20,500	23,920	27,340	30,760	34,170	37,590	41,010	44,420	47,840	51,260	54,680	58,090	61,510	64,930	68,340
15½	27,030	31,530	36,040	40,540	45,050	49,550	54,060	58,560	63,070	67,570	72,080	76,580	81,090	85,590	90,090
17½	34,450	40,200	45,940	51,680	57,420	63,160	68,910	74,650	80,390	86,130	91,880	97,620	103,360	109,100	114,840
19½	42,780	49,910	57,040	64,170	71,300	78,430	85,560	92,690	99,820	106,950	114,080	121,210	128,340	135,460	142,590
15½ × 15½	31,030	36,200	41,380	46,550	51,720	56,890	62,060	67,240	72,410	77,580	82,750	87,920	93,100	98,270	103,440
17½	39,560	46,150	52,740	59,340	65,930	72,520	79,110	85,710	92,300	98,890	105,490	112,080	118,670	125,260	131,860
19½	49,120	57,300	65,490	73,670	81,860	90,040	98,230	106,420	114,600	122,790	130,970	139,160	147,340	155,530	163,720
17½ × 17½	44,660	52,110	59,550	66,990	74,440	81,880	89,320	96,770	104,210	111,660	119,100	126,540	133,990	141,430	148,870
19½	55,450	64,700	73,940	83,180	92,420	101,670	110,910	120,150	129,390	138,640	147,880	157,120	166,360	175,600	184,850
19½ × 19½	61,790	72,090	82,390	92,690	102,980	113,280	123,580	133,880	144,180	154,480	164,770	175,070	185,370	195,670	205,970

*For species corresponding to these working stresses, see Table 2, Column headed "Stress at Extreme Fibre".

WEIGHT OF STRUCTURAL TIMBERS (Full Sizes) IN POUNDS PER LINEAR FOOT

CALCULATED FROM WEIGHTS PER CUBIC FOOT

TABLE 6

Weight in Pounds per Cubic Foot of Principal Canadian Woods (air-dry)	
Species	Weight in Pounds
Cedar, Eastern	21
Cedar, Western	23
Douglas Fir, Coast	34
Douglas Fir, Mountain	32
Fir, Amabilis	27
Fir, Balsam	24
Hemlock, Eastern	29
Hemlock, Western	30
Larch (Tamarack)	35
Larch, Western	38
Pine, Jack	31
Pine, Lodgepole	29
Pine, Red	28
Pine, Western White	26
Pine, Ponderosa	32
Pine, White	27
Spruce, Black	30
Spruce, Engelmann	27
Spruce, Red	28
Spruce, Sitka	27
Spruce, White	26
Beech	46
Birch, Yellow	43
Elm, Red	42
Elm, White	39
Maple, Sugar	46
Oak, Red	43
Oak, White	47

Size in Inches	Pounds per Cubic Foot at 12% Moisture Content*										
	20	21	22	23	24	25	26	27	28	29	30
2 × 2	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.8
3	0.8	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3
4	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7
6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.5
8	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3
10	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.8	3.9	4.0	4.2
12	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.5	4.7	4.8	5.0
14	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.8
16	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6.0	6.2	6.4	6.7
18	5.0	5.3	5.5	5.8	6.0	6.3	6.5	6.8	7.0	7.3	7.5
20	5.6	5.8	6.1	6.4	6.7	6.9	7.2	7.5	7.8	8.1	8.3
3 × 3	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9
4	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.5
6	2.5	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.8
8	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.5	4.7	4.8	5.0
10	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.2
12	5.0	5.3	5.5	5.8	6.0	6.3	6.5	6.8	7.0	7.3	7.5
14	5.8	6.1	6.4	6.7	7.0	7.3	7.6	7.9	8.2	8.5	8.8
16	6.7	7.0	7.3	7.7	8.0	8.3	8.7	9.0	9.3	9.7	10.0
18	7.5	7.9	8.3	8.6	9.0	9.4	9.8	10.1	10.5	10.9	11.3
20	8.3	8.8	9.2	9.6	10.0	10.4	10.8	11.3	11.7	12.1	12.5
4 × 4	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3
6	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.5	4.7	4.8	5.0
8	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6.0	6.2	6.4	6.7
10	5.6	5.8	6.1	6.4	6.7	6.9	7.2	7.5	7.8	8.1	8.3
12	6.7	7.0	7.3	7.7	8.0	8.3	8.7	9.0	9.3	9.7	10.0
14	7.8	8.2	8.6	8.9	9.3	9.7	10.1	10.5	10.9	11.3	11.7
16	8.9	9.3	9.8	10.2	10.7	11.1	11.6	12.0	12.4	12.9	13.3
18	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
20	11.1	11.7	12.2	12.8	13.3	13.9	14.4	15.0	15.6	16.1	16.7
6 × 6	5.0	5.3	5.5	5.8	6.0	6.3	6.5	6.8	7.0	7.3	7.5
8	6.7	7.0	7.3	7.7	8.0	8.3	8.7	9.0	9.3	9.7	10.0
10	8.3	8.8	9.2	9.6	10.0	10.4	10.8	11.3	11.7	12.1	12.5
12	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
14	11.7	12.2	12.8	13.4	14.0	14.6	15.2	15.7	16.3	16.9	17.5
16	13.3	14.0	14.7	15.3	16.0	16.7	17.3	18.0	18.7	19.3	20.0
18	15.0	15.8	16.5	17.3	18.0	18.8	19.5	20.3	21.0	21.8	22.5
20	16.7	17.5	18.3	19.2	20.0	20.8	21.7	22.5	23.3	24.2	25.0
8 × 8	8.9	9.3	9.8	10.2	10.7	11.1	11.6	12.0	12.4	12.9	13.3
10	11.1	11.7	12.2	12.8	13.3	13.9	14.4	15.0	15.6	16.1	16.7
12	13.3	14.0	14.7	15.3	16.0	16.7	17.3	18.0	18.7	19.3	20.0
14	15.6	16.3	17.1	17.9	18.7	19.4	20.2	21.0	21.8	22.6	23.3
16	17.8	18.7	19.6	20.4	21.3	22.2	23.1	24.0	24.9	25.8	26.7
18	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0
20	22.2	23.3	24.4	25.6	26.7	27.8	28.9	30.0	31.1	32.2	33.3
10 × 10	13.9	14.6	15.3	16.0	16.7	17.4	18.1	18.7	19.4	20.1	20.8
12	16.7	17.5	18.3	19.2	20.0	20.8	21.7	22.5	23.3	24.2	25.0
14	19.4	20.4	21.4	22.4	23.3	24.3	25.3	26.2	27.2	28.2	29.2
16	22.2	23.3	24.4	25.6	26.7	27.8	28.9	30.0	31.1	32.2	33.3
18	25.0	26.3	27.5	28.8	30.0	31.3	32.5	33.8	35.0	36.3	37.5
20	27.8	29.2	30.6	31.9	33.3	34.7	36.1	37.5	38.9	40.3	41.7
12 × 12	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0
14	23.3	24.5	25.7	26.8	28.0	29.2	30.3	31.5	32.7	33.8	35.0
16	26.7	28.0	29.3	30.7	32.0	33.3	34.7	36.0	37.3	38.7	40.0
18	30.0	31.5	33.0	34.5	36.0	37.5	39.0	40.5	42.0	43.5	45.0
20	33.3	35.0	36.7	38.3	40.0	41.7	43.3	45.0	46.7	48.3	50.0
14 × 14	27.2	28.6	29.9	31.3	32.7	34.0	35.4	36.7	38.1	39.5	40.8
16	31.1	32.7	34.2	35.8	37.3	38.9	40.4	42.0	43.6	45.1	46.7
18	35.0	36.8	38.5	40.3	42.0	43.8	45.5	47.3	49.0	50.8	52.5
20	38.9	40.8	42.8	44.7	46.7	48.6	50.6	52.5	54.4	56.4	58.3
16 × 16	35.6	37.3	39.1	40.9	42.7	44.4	46.2	48.0	49.8	51.6	53.3
18	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0
20	44.4	46.7	48.9	51.1	53.3	55.6	57.8	60.0	62.2	64.4	66.7
18 × 18	45.0	47.3	49.5	51.8	54.0	56.3	58.5	60.8	63.0	65.3	67.5
20	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5	75.0
20 × 20	55.6	58.3	61.1	63.9	66.7	69.4	72.2	75.0	77.8	80.6	83.3

*Air-dry

WEIGHT OF STRUCTURAL TIMBERS (Full Sizes) IN POUNDS PER LINEAR FOOT

CALCULATED FROM WEIGHTS PER CUBIC FOOT

Pounds per Cubic Foot at 12% Moisture Content*

31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
.09	.09	.09	.09	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4
1.3	1.3	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.1
1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7	2.8
2.6	2.7	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4	3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.1	4.2
3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.6
4.3	4.4	4.6	4.7	4.9	5.0	5.1	5.3	5.4	5.6	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.7	6.8	6.9
5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3
6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.7	8.9	9.1	9.3	9.5	9.7
6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4	8.7	8.9	9.1	9.3	9.6	9.8	10.0	10.2	10.4	10.7	10.9	11.1
7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	10.3	10.5	10.8	11.0	11.3	11.5	11.8	12.0	12.3	12.5
8.6	8.9	9.2	9.4	9.7	10.0	10.3	10.6	10.8	11.1	11.4	11.7	11.9	12.2	12.5	12.8	13.1	13.3	13.6	13.9
1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.8	2.9	2.9	3.0	3.1	3.1
2.6	2.7	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4	3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.1	4.2
3.9	4.0	4.1	4.3	4.4	4.5	4.6	4.8	4.9	5.0	5.1	5.3	5.4	5.5	5.6	5.8	5.9	6.0	6.1	6.3
5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3
6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7	9.0	9.2	9.4	9.6	9.8	10.0	10.2	10.4
7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	10.3	10.5	10.8	11.0	11.3	11.5	11.8	12.0	12.3	12.5
9.0	9.3	9.6	9.9	10.2	10.5	10.8	11.1	11.4	11.7	12.0	12.3	12.5	12.8	13.1	13.4	13.7	14.0	14.3	14.6
10.3	10.7	11.0	11.3	11.7	12.0	12.3	12.7	13.0	13.3	13.7	14.0	14.3	14.7	15.0	15.3	15.7	16.0	16.3	16.7
11.6	12.0	12.4	12.8	13.1	13.5	13.9	14.3	14.6	15.0	15.4	15.8	16.1	16.5	16.9	17.3	17.6	18.0	18.4	18.8
12.9	13.3	13.8	14.2	14.6	15.0	15.4	15.8	16.3	16.7	17.1	17.5	17.9	18.3	18.8	19.2	19.6	20.0	20.4	20.8
3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.6
5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3
6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4	8.7	8.9	9.1	9.3	9.6	9.8	10.0	10.2	10.4	10.7	10.9	11.1
8.6	8.9	9.2	9.4	9.7	10.0	10.3	10.6	10.8	11.1	11.4	11.7	11.9	12.2	12.5	12.8	13.1	13.3	13.6	13.9
10.3	10.7	11.0	11.3	11.7	12.0	12.3	12.7	13.0	13.3	13.7	14.0	14.3	14.7	15.0	15.3	15.7	16.0	16.3	16.7
12.1	12.4	12.8	13.2	13.6	14.0	14.4	14.8	15.2	15.6	15.9	16.3	16.7	17.1	17.5	17.9	18.3	18.7	19.1	19.4
13.8	14.2	14.7	15.1	15.6	16.0	16.4	16.9	17.3	17.8	18.2	18.7	19.1	19.6	20.0	20.4	20.9	21.3	21.8	22.2
15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
17.2	17.8	18.3	18.9	19.4	20.0	20.6	21.1	21.7	22.2	22.8	23.3	23.9	24.4	25.0	25.6	26.1	26.7	27.2	27.8
7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	10.3	10.5	10.8	11.0	11.3	11.5	11.8	12.0	12.3	12.5
10.3	10.7	11.0	11.3	11.7	12.0	12.3	12.7	13.0	13.3	13.7	14.0	14.3	14.7	15.0	15.3	15.7	16.0	16.3	16.7
12.9	13.3	13.8	14.2	14.6	15.0	15.4	15.8	16.3	16.7	17.1	17.5	17.9	18.3	18.8	19.2	19.6	20.0	20.4	20.8
15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
18.1	18.7	19.2	19.8	20.4	21.0	21.6	22.2	22.7	23.3	23.9	24.5	25.1	25.7	26.2	26.8	27.4	28.0	28.6	29.2
20.7	21.3	22.0	22.7	23.3	24.0	24.7	25.3	26.0	26.7	27.3	28.0	28.7	29.3	30.0	30.7	31.3	32.0	32.7	33.3
23.3	24.0	24.8	25.5	26.3	27.0	27.8	28.5	29.3	30.0	30.8	31.5	32.3	33.0	33.8	34.5	35.3	36.0	36.8	37.5
25.8	26.7	27.5	28.3	29.2	30.0	30.8	31.7	32.5	33.3	34.2	35.0	35.8	36.7	37.5	38.3	39.2	40.0	40.8	41.7
13.8	14.2	14.7	15.1	15.6	16.0	16.4	16.9	17.3	17.8	18.2	18.7	19.1	19.6	20.0	20.4	20.9	21.3	21.8	22.2
17.2	17.8	18.3	18.9	19.4	20.0	20.6	21.1	21.7	22.2	22.8	23.3	23.9	24.4	25.0	25.6	26.1	26.7	27.2	27.8
20.7	21.3	22.0	22.7	23.3	24.0	24.7	25.3	26.0	26.7	27.3	28.0	28.7	29.3	30.0	30.7	31.3	32.0	32.7	33.3
24.1	24.9	25.7	26.4	27.2	28.0	28.8	29.6	30.3	31.1	31.9	32.7	33.4	34.2	35.0	35.8	36.6	37.3	38.1	38.9
27.6	28.4	29.3	30.2	31.1	32.0	32.9	33.8	34.7	35.6	36.4	37.3	38.2	39.1	40.0	40.8	41.8	42.7	43.6	44.4
31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	47.0	48.0	49.0	50.0
34.4	35.6	36.7	37.8	38.9	40.0	41.1	42.2	43.3	44.4	45.6	46.7	47.8	48.9	50.0	51.1	52.2	53.3	54.4	55.6
21.5	22.2	22.9	23.6	24.3	25.0	25.7	26.4	27.1	27.8	28.5	29.2	29.9	30.6	31.2	31.9	32.6	33.3	34.0	34.7
25.8	26.7	27.5	28.3	29.2	30.0	30.8	31.7	32.5	33.3	34.2	35.0	35.8	36.7	37.5	38.3	39.2	40.0	40.8	41.7
30.1	31.1	32.1	33.1	34.0	35.0	36.0	36.9	37.9	38.9	39.9	40.8	41.8	42.8	43.7	44.7	45.7	46.7	47.6	48.6
34.4	35.6	36.7	37.8	38.9	40.0	41.1	42.2	43.3	44.4	45.6	46.7	47.8	48.9	50.0	51.1	52.2	53.3	54.4	55.6
38.8	40.0	41.3	42.5	43.8	45.0	46.3	47.5	48.8	50.0	51.3	52.5	53.8	55.0	56.3	57.5	58.8	60.0	61.3	62.5
43.1	44.4	45.8	47.2	48.6	50.0	51.4	52.8	54.2	55.6	56.9	58.3	59.7	61.1	62.5	63.9	65.3	66.7	68.1	69.4
31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	47.0	48.0	49.0	50.0
36.2	37.3	38.5	39.7	40.8	42.0	43.2	44.3	45.5	46.7	47.8	49.0	50.2	51.3	52.5	53.7	54.8	56.0	57.2	58.3
41.3	42.7	44.0	45.3	46.7	48.0	49.3	50.7	52.0	53.3	54.7	56.0	57.3	58.7	60.0	61.3	62.7	64.0	65.3	66.7
46.5	48.0	49.5	51.0	52.5	54.0	55.5	57.0	58.5	60.0	61.5	63.0	64.5	66.0	67.5	69.0	70.5	72.0	73.5	75.0
51.7	53.3	55.0	56.7	58.3	60.0	61.7	63.3	65.0	66.7	68.3	70.0	71.7	73.3	75.0	76.7	78.3	80.0	81.7	83.3
42.2	43.6	44.9	46.3	47.6	49.0	50.4	51.7	53.1	54.4	55.8	57.2	58.5	59.9	61.2	62.6	64.0	65.3	66.7	68.1
48.2	49.8	51.3	52.9	54.4	56.0	57.6	59.1	60.7	62.2	63.8	65.3	66.9	68.4	70.0	71.6	73.1	74.7	76.2	77.8
54.3	56.0	57.8	59.5	61.3	63.0	64.8	66.5	68.3	70.0	71.8	73.5	75.3	77.0	78.8	80.5	82.3	84.0	85.8	87.5
60.3	62.2	64.2	66.1	68.1	70.0	71.9	73.9	75.8	77.8	79.7	81.7	83.6	85.6	87.5	89.4	91.4	93.3	95.3	97.2
55.1	56.9	58.7	60.4	62.2	64.0	65.8	67.7	69.3	71.1	72.9	74.7	76.4	78.2	80.0	81.8	83.6	85.3	87.1	88.9
62.0	64.0	66.0	68.0	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0	92.0	94.0	96.0	98.0	100.0
68.9	71.1	73.3	75.6	77.8	80.0	82.2	84.4	86.7	88.9	91.1	93.3	95.6	97.8	100.0	102.2	104.4	106.7	108.9	111.1
69.8	72.0	74.3	76.5	78.8	81.0	83.3	85.5	87.8	90.0	92.3	94.5	96.8	99.0	101.3	103.5	105.8	108.0	110.3	112.5
77.5	80.0	82.5	85.0	87.5	90.0	92.5	95.0	97.5	100.0	102.5	105.0	107.5	110.0	112.5	115.0	117.5	120.0	122.5	125.0
86.1	88.9	91.7	94.4	97.2	100.0	102.8	105.6	108.3	111.1	113.9	116.7	119.4	122.2	125.0	127.8	130.6	133.3	136.1	138.9

*Air-dry

TABLE 7

WEIGHT OF STRUCTURAL TIMBERS (Dressed Sizes) IN POUNDS PER LINEAR FOOT

CALCULATED FROM WEIGHTS PER CUBIC FOOT

Weight in Pounds per Cubic Foot of Principal Canadian Woods (air-dry)

Species	Weight in Pounds
Cedar, Eastern	21
Cedar, Western	23
Douglas Fir, Coast	34
Douglas Fir, Mountain	32
Fir, Amabilis	27
Fir, Balsam	24
Hemlock, Eastern	29
Hemlock, Western	30
Larch (Tamarack)	35
Larch, Western	38
Pine, Jack	31
Pine, Lodgepole	29
Pine, Red	28
Pine, Western White	26
Pine, Ponderosa	32
Pine, White	27
Spruce, Black	30
Spruce, Engelmann	27
Spruce, Red	28
Spruce, Sitka	27
Spruce, White	26
Beech	46
Birch, Yellow	43
Elm, Red	42
Elm, White	39
Maple, Sugar	46
Oak, Red	43
Oak, White	47

Size in Inches	Pounds per Cubic Foot at 12% Moisture Content*										
	20	21	22	23	24	25	26	27	28	29	30
1⅝ × 1⅝	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6
2⅝	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9
3⅝	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	1.1	1.2	1.2
5⅝	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.8	1.9
7½	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5
9½	2.1	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
11½	2.6	2.7	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.8	3.9
13½	3.0	3.2	3.4	3.5	3.7	3.8	4.0	4.1	4.3	4.4	4.6
15½	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.9	5.1	5.2
17½	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9
19½	4.4	4.6	4.8	5.1	5.3	5.5	5.7	5.9	6.2	6.4	6.6
2⅝ × 2⅝	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4
3⅝	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0
5⅝	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1
7½	2.7	2.9	3.0	3.1	3.3	3.4	3.6	3.7	3.8	4.0	4.1
9½	3.5	3.6	3.8	4.0	4.2	4.3	4.5	4.7	4.8	5.0	5.2
11½	4.2	4.4	4.6	4.8	5.0	5.2	5.5	5.7	5.9	6.1	6.3
13½	4.9	5.2	5.4	5.7	5.9	6.2	6.4	6.6	6.9	7.1	7.4
15½	5.7	5.9	6.2	6.5	6.8	7.1	7.3	7.6	7.9	8.2	8.5
17½	6.4	6.7	7.0	7.3	7.7	8.0	8.3	8.6	8.9	9.3	9.6
19½	7.1	7.5	7.8	8.2	8.5	8.9	9.2	9.6	10.0	10.3	10.7
3⅝ × 3⅝	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.7
5⅝	2.8	3.0	3.1	3.3	3.4	3.5	3.7	3.8	4.0	4.1	4.2
7½	3.8	4.0	4.2	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7
9½	4.8	5.0	5.3	5.5	5.7	6.0	6.2	6.5	6.7	6.9	7.2
11½	5.8	6.1	6.4	6.7	6.9	7.2	7.5	7.8	8.1	8.4	8.7
13½	6.8	7.1	7.5	7.8	8.2	8.5	8.8	9.2	9.5	9.9	10.2
15½	7.8	8.2	8.6	9.0	9.4	9.8	10.1	10.5	10.9	11.3	11.7
17½	8.8	9.3	9.7	10.1	10.6	11.0	11.5	11.9	12.3	12.8	13.2
19½	9.8	10.3	10.8	11.3	11.8	12.3	12.8	13.3	13.7	14.2	14.7
5½ × 5½	4.2	4.4	4.6	4.8	5.0	5.3	5.5	5.7	5.9	6.1	6.3
7½	5.7	6.0	6.3	6.6	6.9	7.2	7.4	7.7	8.0	8.3	8.6
9½	7.3	7.6	8.0	8.3	8.7	9.1	9.4	9.8	10.2	10.5	10.9
11½	8.8	9.2	9.7	10.1	10.5	11.0	11.4	11.9	12.3	12.7	13.2
13½	10.3	10.8	11.3	11.9	12.4	12.9	13.4	13.9	14.4	15.0	15.5
15½	11.8	12.4	13.0	13.6	14.2	14.8	15.4	16.0	16.6	17.2	17.8
17½	13.4	14.0	14.7	15.4	16.0	16.7	17.4	18.0	18.7	19.4	20.1
19½	14.9	15.6	16.4	17.1	17.9	18.6	19.4	20.1	20.9	21.6	22.3
7½ × 7½	7.8	8.2	8.6	9.0	9.4	9.8	10.2	10.5	10.9	11.3	11.7
9½	9.9	10.4	10.9	11.4	11.9	12.4	12.9	13.4	13.9	14.3	14.8
11½	12.0	12.6	13.2	13.8	14.4	15.0	15.6	16.2	16.8	17.4	18.0
13½	14.1	14.8	15.5	16.2	16.9	17.6	18.3	19.0	19.7	20.4	21.1
15½	16.1	17.0	17.8	18.6	19.4	20.2	21.0	21.8	22.6	23.4	24.2
17½	18.2	19.1	20.1	21.0	21.9	22.8	23.7	24.6	25.5	26.4	27.3
19½	20.3	21.3	22.3	23.4	24.4	25.4	26.4	27.4	28.4	29.5	30.5
9½ × 9½	12.5	13.2	13.8	14.4	15.0	15.7	16.3	16.9	17.5	18.2	18.8
11½	15.2	15.9	16.7	17.4	18.2	19.0	19.7	20.5	21.2	22.0	22.8
13½	17.8	18.7	19.6	20.5	21.4	22.3	23.2	24.0	24.9	25.8	26.7
15½	20.5	21.5	22.5	23.5	24.5	25.6	26.6	27.6	28.6	29.7	30.7
17½	23.1	24.2	25.4	26.6	27.7	28.9	30.0	31.2	32.3	33.5	34.6
19½	25.7	27.0	28.3	29.6	30.9	32.2	33.4	34.7	36.0	37.3	38.6
11½ × 11½	18.4	19.3	20.2	21.1	22.0	23.0	23.9	24.8	25.7	26.6	27.6
13½	21.6	22.6	23.7	24.8	25.9	27.0	28.0	29.1	30.2	31.3	32.3
15½	24.8	26.0	27.2	28.5	29.7	30.9	32.2	33.4	34.7	35.9	37.1
17½	28.0	29.3	30.7	32.1	33.5	34.9	36.3	37.7	39.1	40.5	41.9
19½	31.1	32.7	34.3	35.8	37.4	38.9	40.5	42.0	43.6	45.2	46.7
13½ × 13½	25.3	26.6	27.8	29.1	30.4	31.6	32.9	34.2	35.4	36.7	38.0
15½	29.1	30.5	32.0	33.4	34.9	36.3	37.8	39.2	40.7	42.1	43.6
17½	32.8	34.5	36.1	37.7	39.4	41.0	42.7	44.3	45.9	47.6	49.2
19½	36.6	38.4	40.2	42.0	43.9	45.7	47.5	49.4	51.2	53.0	54.8
15½ × 15½	33.4	35.0	36.7	38.4	40.0	41.7	43.4	45.0	46.7	48.4	50.1
17½	37.7	39.6	41.4	43.3	45.2	47.1	49.0	50.9	52.7	54.6	56.5
19½	42.0	44.1	46.2	48.3	50.4	52.5	54.6	56.7	58.8	60.9	63.0
17½ × 17½	42.5	44.7	46.8	48.9	51.0	53.2	55.3	57.4	59.5	61.7	63.8
19½	47.4	49.8	52.1	54.5	56.9	59.2	61.6	64.0	66.4	68.7	71.1
19½ × 19½	52.8	55.5	58.1	60.7	63.4	66.0	68.7	71.3	73.9	76.6	79.2

*Air-dry

WEIGHT OF STRUCTURAL TIMBERS (Dressed Sizes) IN POUNDS PER LINEAR FOOT

CALCULATED FROM WEIGHTS PER CUBIC FOOT

Pounds per Cubic Foot at 12% Moisture Content*

31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9
0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.5
1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0
2.0	2.0	2.1	2.2	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.7	2.8	2.9	2.9	3.0	3.0	3.1	3.2
2.6	2.7	2.8	2.9	3.0	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.6	3.7	3.8	3.9	4.0	4.1	4.1	4.2
3.3	3.4	3.5	3.6	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.3	5.4
4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.3	5.5	5.6	5.7	5.8	6.0	6.1	6.2	6.4	6.5
4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1	6.2	6.4	6.6	6.7	6.9	7.0	7.2	7.3	7.5	7.6
5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.6	6.8	7.0	7.2	7.3	7.5	7.7	7.9	8.0	8.2	8.4	8.6	8.7
6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9
6.8	7.0	7.3	7.5	7.7	7.9	8.1	8.4	8.6	8.8	9.0	9.2	9.5	9.7	9.9	10.1	10.3	10.6	10.8	11.0
1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.3	2.3	2.4
2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.2	3.2	3.3
3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1
4.2	4.4	4.5	4.6	4.8	4.9	5.1	5.2	5.3	5.5	5.6	5.7	5.9	6.0	6.2	6.3	6.4	6.6	6.7	6.8
5.4	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	6.9	7.1	7.3	7.4	7.6	7.8	8.0	8.1	8.3	8.5	8.7
6.5	6.7	6.9	7.1	7.3	7.5	7.8	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.4	9.6	9.9	10.1	10.3	10.5
7.6	7.9	8.1	8.4	8.6	8.9	9.1	9.4	9.6	9.8	10.1	10.3	10.6	10.8	11.1	11.3	11.6	11.8	12.1	12.3
8.8	9.0	9.3	9.6	9.9	10.2	10.5	10.7	11.0	11.3	11.6	11.9	12.1	12.4	12.7	13.0	13.3	13.6	13.8	14.1
9.9	10.2	10.5	10.8	11.2	11.5	11.8	12.1	12.4	12.8	13.1	13.4	13.7	14.0	14.4	14.7	15.0	15.3	15.6	16.0
11.0	11.4	11.7	12.1	12.4	12.8	13.2	13.5	13.9	14.2	14.6	14.9	15.3	15.6	16.0	16.4	16.7	17.1	17.4	17.8
2.8	3.0	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6
4.4	4.5	4.7	4.8	5.0	5.1	5.2	5.4	5.5	5.7	5.8	5.9	6.1	6.2	6.4	6.5	6.7	6.8	6.9	7.1
5.9	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.4
7.4	7.7	7.9	8.1	8.4	8.6	8.8	9.1	9.3	9.6	9.8	10.0	10.3	10.5	10.8	11.0	11.2	11.5	11.7	12.0
9.0	9.3	9.6	9.8	10.1	10.4	10.7	11.0	11.3	11.6	11.9	12.2	12.4	12.7	13.0	13.3	13.6	13.9	14.2	14.5
10.5	10.9	11.2	11.6	11.9	12.2	12.6	12.9	13.3	13.6	13.9	14.3	14.6	15.0	15.3	15.6	16.0	16.3	16.7	17.0
12.1	12.5	12.9	13.3	13.7	14.0	14.4	14.8	15.2	15.6	16.0	16.4	16.8	17.2	17.6	17.9	18.3	18.7	19.1	19.5
13.7	14.1	14.5	15.0	15.4	15.9	16.3	16.7	17.2	17.6	18.1	18.5	18.9	19.4	19.8	20.3	20.7	21.1	21.6	22.0
15.2	15.7	16.2	16.7	17.2	17.7	18.2	18.7	19.1	19.6	20.1	20.6	21.1	21.6	22.1	22.6	23.1	23.6	24.1	24.5
6.5	6.7	6.9	7.1	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.5	9.7	9.9	10.1	10.3	10.5
8.9	9.2	9.5	9.7	10.0	10.3	10.6	10.9	11.2	11.5	11.7	12.0	12.3	12.6	12.9	13.2	13.5	13.8	14.0	14.3
11.2	11.6	12.0	12.3	12.7	13.1	13.4	13.8	14.2	14.5	14.9	15.2	15.6	16.0	16.3	16.7	17.1	17.4	17.8	18.1
13.6	14.1	14.5	14.9	15.4	15.8	16.3	16.7	17.1	17.6	18.0	18.4	18.9	19.3	19.8	20.2	20.6	21.1	21.5	22.0
16.0	16.5	17.0	17.5	18.0	18.6	19.1	19.6	20.1	20.6	21.1	21.7	22.2	22.7	23.2	23.7	24.2	24.8	25.3	25.8
18.4	18.9	19.5	20.1	20.7	21.3	21.9	22.5	23.1	23.7	24.3	24.9	25.5	26.0	26.6	27.2	27.8	28.4	29.0	29.6
20.7	21.4	22.1	22.7	23.4	24.1	24.7	25.4	26.1	26.7	27.4	28.1	28.7	29.4	30.1	30.7	31.4	32.1	32.8	33.4
23.1	23.8	24.6	25.3	26.1	26.8	27.6	28.3	29.0	29.8	30.5	31.3	32.0	32.8	33.5	34.3	35.0	35.8	36.5	37.2
12.1	12.5	12.9	13.3	13.7	14.1	14.5	14.8	15.2	15.6	16.0	16.4	16.8	17.2	17.6	18.0	18.4	18.7	19.1	19.5
15.3	15.8	16.3	16.8	17.3	17.8	18.3	18.8	19.3	19.8	20.3	20.8	21.3	21.8	22.3	22.8	23.3	23.8	24.2	24.7
18.6	19.2	19.8	20.4	21.0	21.5	22.1	22.7	23.3	23.9	24.5	25.1	25.7	26.3	26.9	27.5	28.1	28.7	29.3	29.9
21.8	22.5	23.2	23.9	24.6	25.3	26.0	26.7	27.4	28.1	28.8	29.5	30.2	30.9	31.6	32.3	33.0	33.8	34.5	35.2
25.0	25.8	26.6	27.4	28.3	29.1	29.9	30.7	31.5	32.3	33.1	33.9	34.7	35.5	36.3	37.1	37.9	38.7	39.6	40.4
28.3	29.2	30.1	31.0	31.9	32.8	33.7	34.6	35.5	36.5	37.4	38.3	39.2	40.1	41.0	41.9	42.8	43.8	44.7	45.6
31.5	32.5	33.5	34.5	35.5	36.6	37.6	38.6	39.6	40.6	41.6	42.7	43.7	44.7	45.7	46.7	47.7	48.8	49.8	50.8
19.4	20.1	20.7	21.3	21.9	22.6	23.2	23.8	24.4	25.1	25.7	26.3	26.9	27.6	28.2	28.8	29.5	30.1	30.7	31.3
23.5	24.3	25.0	25.8	26.6	27.3	28.1	28.8	29.6	30.3	31.1	31.9	32.6	33.4	34.1	34.9	35.7	36.4	37.2	37.9
27.6	28.5	29.4	30.3	31.2	32.1	33.0	33.8	34.7	35.6	36.5	37.4	38.3	39.2	40.1	41.0	41.9	42.8	43.6	44.5
31.7	32.7	33.7	34.8	35.8	36.8	37.8	38.9	39.9	40.9	41.9	42.9	44.0	45.0	46.0	47.0	48.1	49.1	50.1	51.1
35.8	36.9	38.1	39.3	40.4	41.6	42.7	43.9	45.0	46.2	47.3	48.5	49.6	50.8	52.0	53.1	54.3	55.4	56.6	57.7
39.9	41.2	42.5	43.7	45.0	46.3	47.6	48.9	50.2	51.5	52.7	54.0	55.3	56.6	57.9	59.2	60.5	61.8	63.0	64.3
28.5	29.4	30.3	31.2	32.1	33.1	34.0	34.9	35.8	36.7	37.7	38.6	39.5	40.4	41.3	42.2	43.2	44.1	45.0	45.9
33.4	34.5	35.6	36.7	37.7	38.8	39.9	41.0	42.0	43.1	44.2	45.3	46.4	47.4	48.5	49.6	50.7	51.8	52.8	53.9
38.4	39.6	40.8	42.1	43.3	44.6	45.8	47.0	48.3	49.5	50.8	52.0	53.2	54.5	55.7	56.9	58.2	59.4	60.7	61.9
43.3	44.7	46.1	47.5	48.9	50.3	51.7	53.1	54.5	55.9	57.3	58.7	60.1	61.5	62.9	64.3	65.7	67.1	68.5	69.9
48.3	49.8	51.4	52.9	54.5	56.1	57.6	59.2	60.7	62.3	63.8	65.4	67.0	68.5	70.1	71.6	73.2	74.7	76.3	77.9
39.2	40.5	41.8	43.0	44.3	45.6	46.8	48.1	49.4	50.6	51.9	53.2	54.4	55.7	57.0	58.2	59.5	60.8	62.0	63.3
45.0	46.5	48.0	49.4	50.9	52.3	53.8	55.2	56.7	58.1	59.6	61.0	62.5	63.9	65.4	66.8	68.3	69.8	71.2	72.7
50.9	52.5	54.1	55.8	57.4	59.1	60.7	62.3	64.0	65.6	67.3	68.9	70.5	72.2	73.8	75.5	77.1	78.8	80.4	82.0
56.7	58.5	60.3	62.2	64.0	65.8	67.6	69.5	71.3	73.1	75.0	76.8	78.6	80.4	82.3	84.1	85.9	87.8	89.6	91.4
51.7	53.4	55.1	56.7	58.4	60.1	61.7	63.4	65.1	66.7	68.4	70.1	71.7	73.4	75.1	76.7	78.4	80.1	81.8	83.4
58.4	60.3	62.2	64.0	65.9	67.8	69.7	71.6	73.5	75.3	77.2	79.1	81.0	82.9	84.8	86.6	88.5	90.4	92.3	94.2
65.1	67.2	69.3	71.4	73.5	75.6	77.7	79.8	81.9	84.0	86.1	88.2	90.3	92.4	94.5	96.6	98.7	100.7	102.8	104.9
65.9	68.1	70.2	72.3	74.4	76.6	78.7	80.8	82.9	85.1	87.2	89.3	91.4	93.6	95.7	97.8	100.0	102.1	104.2	106.3
73.5	75.8	78.2	80.6	82.9	85.3	87.7	90.1	92.4	94.8	97.2	99.5	101.9	104.3	106.6	109.0	111.4	113.7	116.1	118.5
81.9	84.5	87.1	89.8	92.4	95.1	97.7	100.3	103.9	105.6	108.3	110.9	113.5	116.2	118.8	121.5	124.1	126.7	129.4	132.0

*Air-dry.

SAFE LOADS FOR JOISTS AND BEAMS, NEGLECTING SHEAR (Full Sizes)*

TABLE 8

SIZE IN INCHES	SAFE ALLOWABLE WORKING STRESS IN BENDING (pounds per square inch)											
	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1900
2 × 2	530	620	710	800	890	980	1,070	1,160	1,240	1,330	1,420	1,510	1,690
3	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200	3,400	3,800
4	2,130	2,490	2,840	3,200	3,560	3,910	4,270	4,620	4,980	5,330	5,690	6,040	6,760
6	4,800	5,600	6,400	7,200	8,000	8,800	9,600	10,400	11,200	12,000	12,800	13,600	15,200
8	8,530	9,960	11,380	12,800	14,220	15,640	17,070	18,490	19,910	21,330	22,760	24,180	27,020
10	13,330	15,560	17,780	20,000	22,220	24,440	26,670	28,890	31,110	33 330	35,560	37,780	42,220
12	19,200	22,400	25,600	28,800	32,000	35,200	38,400	41,600	44,800	48,000	51,200	54,400	60,800
14	26,130	30,490	34,840	39,200	43,560	47,910	52,270	56,620	60,980	65,330	69,690	74,040	82,760
16	34,130	39,820	45,510	51,200	56,890	62,580	68,270	73,960	79,640	85,330	91,020	96,710	108,090
3 × 3	1,800	2,100	2,400	2,700	3,000	3,300	3,600	3,900	4,200	4,500	4,800	5,100	5,700
4	3,200	3,730	4,270	4,800	5,330	5,870	6,400	6,930	7,470	8,000	8,530	9,070	10,130
6	7,200	8,400	9,600	10,800	12,000	13,200	14,400	15,600	16,800	18,000	19,200	20,400	22,800
8	12,800	14,930	17,070	19,200	21,330	23,470	25,600	27,730	29,870	32,000	34,130	36,270	40,530
10	20,000	23,330	26,670	30,000	33,330	36,670	40,000	43,330	46,670	50,000	53,330	56,670	63,330
12	28,800	33,600	38,400	43,200	48,000	52,800	57,600	62,400	67,200	72,000	76,800	81,600	91,200
14	39,200	45,730	52,270	58,800	65,330	71,870	78,400	84,930	91,470	98,000	104,530	111,070	124,130
16	51,200	59,730	68,270	76,800	85,330	93,870	102.400	110,930	119,470	128,000	136,530	145,070	162,130
18	64,800	75,600	86,400	97,200	108,000	118,800	129,600	140,400	151,200	162,000	172,800	183,600	205,200
4 × 4	4,270	4,980	5,690	6,400	7,110	7,820	8,530	9,240	9,960	10,670	11,380	12,090	13,510
6	9,600	11,200	12,800	14,400	16,000	17,600	19,200	20,800	22,400	24,000	25,600	27,200	30,400
8	17,070	19,910	22,760	25,600	28,440	31,290	34,130	36,980	39,820	42,670	45,510	48,360	54,040
10	26,670	31,110	35,560	40,000	44,440	48,890	53,330	57,780	62,220	66,670	71,110	75,560	84,440
12	38,400	44,800	51,200	57,600	64,000	70,400	76,800	83,200	89,600	96,000	102,400	108,800	121,600
14	52,270	60,980	69,690	78,400	87,110	95,820	104,530	113,240	121,960	130,670	139,380	148,090	165,510
16	68,270	79,640	91,020	102,400	113,780	125,160	136,530	147,910	159,290	170,670	182,040	193,420	216,180
18	86,400	100,800	115,200	129,600	144,000	158,400	172,800	187,200	201,600	216,000	230,400	244,800	273,600
20	106,670	124,440	142,220	160,000	177,780	195,560	213,330	231,110	248,890	266,670	284,440	302,220	337,780
6 × 6	14,400	16,800	19,200	21,600	24,000	26,400	28,800	31,200	33,600	36,000	38,400	40,800	45,600
8	25,600	29,870	34,130	38,400	42,670	46,930	51,200	55,470	59,730	64,000	68,270	72,530	81,070
10	40,000	46,670	53,330	60,000	66,670	73,330	80,000	86,670	93,330	100,000	106,670	113,330	126,670
12	57,600	67,200	76,800	86,400	96,000	105,600	115,200	124,800	134,400	144,000	153,600	163,200	182,400
14	78,400	91,470	104,530	117,600	130,670	143,730	156,800	169,870	182,930	196,000	209,070	222,130	248,270
16	102,400	119,470	136,530	153,600	170,670	187,730	204,800	221,870	238,930	256,000	273,070	290,130	324,270
18	129,600	151,200	172,800	194,400	216,000	237,600	259,200	280,800	302,400	324,000	345,600	367,200	410,400
20	160,000	186,670	213,330	240,000	266,670	293,330	320,000	346,670	373,330	400,000	426,670	453,330	506,670
8 × 8	34,130	34,820	45,510	51,200	56,890	62,580	68,270	73,960	79,640	85,330	91,020	96,710	108,090
10	53,330	62,220	71,110	80,000	88,890	97,780	106,670	115,560	124,440	133,330	142,220	151,110	168,890
12	76,800	89,600	102,400	115,200	128,000	140,800	153,600	166,400	179,200	192,000	204,800	217,600	243,200
14	104,530	121,960	139,380	156,800	174,220	191,640	209,070	226,490	243,910	261,330	278,760	296,180	331,020
16	136,530	159,290	182,040	204,800	227,560	250,310	273,070	295,820	318,580	341,330	364,090	386,840	432,360
18	172,800	201,600	232,400	259,200	288,000	316,800	345,600	374,400	403,200	432,000	460,800	489,600	547,200
20	213,330	248,890	284,440	320,000	355,560	391,110	426,670	462,220	497,780	533,330	568,890	604,440	675,560
10 × 10	66,670	77,780	88,890	100,000	111,110	122,220	133,330	144,440	155,560	166,670	177,780	188,890	211,110
12	96,000	112,000	128,000	144,000	160,000	176,000	192,000	208,000	224,000	240,000	256,000	272,000	304,000
14	130,670	152,440	174,220	196,000	217,780	239,560	261,330	283,110	304,890	326,670	348,440	370,220	413,780
16	170,670	199,110	227,560	256,000	284,440	312,890	341,330	369,780	398,220	426,670	455,110	483,560	540,440
18	216,000	252,000	288,000	324,000	360,000	396,000	432,000	468,000	504,000	540,000	576,000	612,000	684,000
20	266,670	311,110	355,560	400,000	444,440	488,890	533,330	577,780	622,220	666,670	711,110	755,560	844,440
12 × 12	115,200	134,400	153,600	172,800	192,000	211,200	230,400	249,600	268,800	288,000	307,200	326,400	364,800
14	156,800	187,930	209,070	235,200	261,330	287,470	313,600	338,730	365,870	392,000	418,130	444,270	496,530
16	204,800	238,930	273,070	307,200	341,330	375,470	409,600	443,730	477,870	512,000	546,130	580,270	648,530
18	259,200	302,400	345,600	388,800	432,000	475,200	518,400	561,600	604,800	648,000	691,200	734,400	820,800
20	320,000	373,330	426,670	480,000	533,330	586,670	640,000	693,330	746,670	800,000	853,330	906,670	1,013,330
14 × 14	182,930	213,420	243,910	274,400	304,890	335,380	365,870	396,360	426,840	457,330	487,820	518,310	579,290
16	238,930	278,760	318,580	358,400	398,220	438,040	477,870	517,690	557,510	597,330	637,160	676,980	756,620
18	302,400	352,800	403,200	453,600	504,000	554,400	604,800	655,200	705,600	756,000	806,400	856,800	957,600
20	373,330	435,560	497,780	560,000	622,220	684,440	746,670	808,890	871,110	933,330	995,560	1,057,780	1,182,220
16 × 16	273,070	318,580	364,090	409,600	455,110	500,620	546,130	591,640	637,160	682,670	728,180	773,690	864,710
18	345,600	403,200	460,800	518,400	576,000	633,600	691,200	748,800	806,400	864,000	921,600	979,200	1,094,400
20	426,670	497,780	568,890	640,000	711,110	782,220	853,330	924,440	995,560	1,066,670	1,137,780	1,208,890	1,351,110
18 × 18	388,800	453,600	518,400	583,200	648,000	712,800	777,600	842,400	907,200	972,000	1,036,800	1,101,600	1,231,200
20	480,000	560,000	640,000	720,000	800,000	880,000	960,000	1,040,000	1,120,000	1,200,000	1,280,000	1,360,000	1,520,000
20 × 20	533,330	622,220	711,110	800,000	888,890	977,780	1,066,670	1,155,560	1,244,440	1,333,330	1,422,220	1,511,110	1,688,890

*To obtain a safe, uniformly distributed load for any span, divide the values in the table by the length of span in feet. If load is concentrated at centre of span, use half of values thus obtained. Check for shear capacity by referring to Table 10.

SAFE LOADS FOR JOISTS AND BEAMS, NEGLECTING SHEAR (Dressed Sizes)*

TABLE 9

SIZE IN INCHES	SAFE ALLOWABLE WORKING STRESS IN BENDING (pounds per square inch)												
	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1900
1⅝ × 1⅝	290	330	380	430	480	520	570	620	670	720	760	810	910
2⅝	750	870	1,000	1,120	1,240	1,370	1,490	1,620	1,740	1,870	1,990	2,120	2,360
3⅝	1,420	1,670	1,900	2,140	2,370	2,610	2,850	3,090	3,320	3,560	3,800	4,030	4,510
5⅝	3,430	4,000	4,570	5,140	5,710	6,280	6,860	7,430	8,000	8,570	9,140	9,710	10,860
7½	6,090	7,110	8,130	9,140	10,160	11,170	12,190	13,200	14,220	15,230	16,250	17,270	19,300
9½	9,780	11,410	13,040	14,670	16,300	17,930	19,550	21,180	22,810	24,440	26,070	27,700	30,960
11½	14,330	16,720	19,100	21,490	23,880	26,270	28,650	31,040	33,430	35,820	38,210	40,590	45,370
13½	19,740	23,030	26,330	29,620	32,910	36,200	39,490	42,780	46,070	49,360	52,650	55,940	62,520
15½	26,030	30,370	34,700	39,040	43,380	47,720	52,050	56,390	60,730	65,070	69,410	73,740	82,420
2⅝ × 2⅝	1,210	1,410	1,610	1,810	2,010	2,210	2,410	2,610	2,810	3,020	3,220	3,420	3,820
3⅝	2,300	2,680	3,070	3,450	3,830	4,220	4,600	4,980	5,370	5,750	6,130	6,520	7,280
5⅝	5,540	6,460	7,380	8,310	9,230	10,150	11,070	12,000	12,920	13,840	14,770	15,690	17,530
7½	9,840	11,480	13,130	14,770	16,410	18,050	19,690	21,330	22,970	24,610	26,250	27,890	31,170
9½	15,790	18,430	21,060	23,690	26,320	28,960	31,590	34,220	36,850	39,490	42,120	44,750	50,010
11½	23,140	27,000	30,860	34,720	38,570	42,430	46,290	50,150	54,000	57,860	61,720	65,570	73,290
13½	31,890	37,210	42,530	47,840	53,160	58,470	63,790	69,100	74,420	79,730	85,050	90,370	101,000
15½	42,040	49,050	56,060	63,070	70,070	77,080	84,090	91,100	98,100	105,110	112,120	119,120	133,140
17½	53,590	62,530	71,460	80,390	89,320	98,260	107,190	116,120	125,050	133,990	142,920	151,850	169,710
3⅝ × 3⅝	3,180	3,710	4,230	4,760	5,290	5,820	6,350	6,880	7,410	7,940	8,470	9,000	10,060
5⅝	7,650	8,920	10,200	11,470	12,740	14,020	15,290	16,570	17,840	19,120	20,390	21,670	24,210
7½	13,590	15,860	18,130	20,390	22,660	24,920	27,190	29,450	31,720	33,980	36,250	38,520	43,050
9½	21,810	25,450	29,080	32,720	36,350	39,990	43,620	47,260	50,890	54,530	58,160	61,800	69,070
11½	31,960	37,290	42,610	47,940	53,270	58,590	63,920	69,250	74,570	79,900	85,230	90,550	101,210
13½	44,040	51,380	58,730	66,070	73,410	80,750	88,090	95,430	102,770	110,110	117,450	124,790	139,470
15½	58,060	67,740	77,410	87,090	96,770	106,440	116,120	125,800	135,470	145,150	154,830	164,500	183,860
17½	74,010	86,350	98,680	111,020	123,350	135,690	148,020	160,360	172,690	185,030	197,360	209,700	234,370
19½	91,890	107,210	122,530	137,840	153,160	168,470	183,790	199,100	214,420	229,730	245,050	260,370	291,000
5½ × 5½	11,090	12,940	14,790	16,640	18,490	20,340	22,180	24,030	25,880	27,730	29,580	31,430	35,120
7½	20,630	24,060	27,500	30,940	34,380	37,810	41,250	44,690	48,130	51,560	55,000	58,440	65,310
9½	33,090	38,610	44,120	49,640	55,150	60,670	66,180	71,700	77,210	82,730	88,250	93,760	104,790
11½	48,490	56,570	64,660	72,740	80,820	88,900	96,980	105,070	113,150	121,230	129,310	137,390	153,560
13½	66,830	77,860	89,100	100,240	111,380	122,510	133,650	144,790	155,930	167,060	178,200	189,340	211,610
15½	88,090	102,770	117,460	132,140	146,820	161,500	176,180	190,870	205,550	220,230	234,910	249,590	278,960
17½	112,290	131,010	149,720	168,440	187,150	205,870	224,580	243,300	262,010	280,730	299,450	318,160	355,590
19½	139,430	162,660	185,900	209,140	232,380	255,610	278,850	302,090	325,330	348,560	371,800	395,040	441,510
7½ × 7½	28,130	32,810	37,500	42,190	46,880	51,560	56,250	60,940	65,630	70,310	75,000	79,690	89,060
9½	45,130	52,650	60,170	67,690	75,210	82,730	90,250	97,770	105,290	112,810	120,330	127,850	142,900
11½	66,130	77,150	88,170	99,190	110,210	121,230	132,250	143,270	154,290	165,310	176,330	187,350	209,400
13½	91,130	106,310	121,500	136,690	151,880	167,060	182,250	197,440	212,630	227,810	243,000	258,190	288,560
15½	120,130	140,150	160,170	180,190	200,210	220,230	240,250	260,270	280,290	300,310	320,330	340,350	380,400
17½	153,130	178,650	204,170	229,690	255,210	280,730	306,250	331,770	357,290	382,810	408,330	433,850	484,900
19½	190,130	221,810	253,500	285,190	316,880	348,560	380,250	411,940	443,630	475,310	507,000	538,690	602,060
9½ × 9½	57,160	66,690	76,210	85,740	95,260	104,790	114,320	123,840	133,370	142,900	152,420	161,950	181,000
11½	83,760	97,720	111,680	125,640	139,600	153,560	167,520	181,480	195,440	209,400	223,360	237,320	265,230
13½	115,430	134,660	153,900	173,140	192,380	211,610	230,850	250,090	269,330	288,560	307,800	327,040	365,510
15½	152,160	177,520	202,880	228,240	253,600	278,960	304,320	329,680	355,040	380,400	405,760	431,120	481,830
17½	193,960	226,290	258,610	290,940	323,260	355,590	387,920	420,240	452,570	484,900	517,220	549,550	614,200
19½	240,830	280,960	321,100	316,240	401,380	441,510	481,650	521,790	561,930	602,060	642,200	682,340	762,610
11½ × 11½	101,390	118,290	135,190	152,090	168,990	185,880	202,780	219,680	236,580	253,480	270,380	287,280	321,070
13½	139,730	163,010	186,300	209,590	232,880	256,160	279,450	302,740	326,030	349,310	372,600	395,890	442,460
15½	184,190	214,890	245,590	276,290	306,990	337,680	368,380	399,080	429,780	460,480	491,180	521,880	583,270
17½	234,790	273,920	313,060	352,190	391,320	430,450	469,580	508,720	547,850	586,980	626,110	665,240	743,710
19½	291,530	340,110	388,700	437,290	485,880	534,460	583,050	631,640	680,230	728,810	777,400	825,990	923,160
13½ × 13½	164,030	191,360	218,700	246,040	273,380	300,710	328,050	355,390	382,730	410,060	437,400	464,740	519,410
15½	216,230	252,260	288,300	324,340	360,370	396,410	432,450	468,490	504,520	540,560	576,600	612,640	684,710
17½	275,630	321,560	367,500	413,440	459,380	505,310	551,250	597,190	643,130	689,060	735,000	780,940	872,810
19½	342,230	399,260	456,300	513,340	570,380	672,410	684,450	741,490	798,530	855,560	912,600	969,640	1,083,710
15½ × 15½	248,260	289,630	331,010	372,390	413,760	455,140	496,520	537,890	579,270	620,650	662,020	703,400	786,150
17½	316,460	369,200	421,950	474,690	527,430	580,170	632,920	685,660	738,400	791,150	843,890	896,630	1,002,120
19½	392,930	458,410	523,900	589,390	654,880	720,360	785,850	851,340	916,830	982,310	1,047,800	1,113,290	1,244,260
17½ × 17½	357,290	416,840	476,390	535,940	595,490	655,040	714,580	774,130	833,680	893,230	952,780	1,012,330	1,131,420
19½	443,630	517,560	591,500	665,440	739,380	813,310	887,250	961,190	1,035,130	1,109,060	1,183,000	1,256,940	1,404,810
19½ × 19½	494,330	576,710	659,100	741,490	823,880	906,260	988,650	1,071,040	1,153,430	1,235,810	1,318,200	1,400,590	1,565,360

*To obtain a safe, uniformly distributed load for any span, divide the values in the table by the length of span in feet. If load is concentrated at centre of span, use half of values thus obtained. Check for shear capacity by referring to Table 10.

SAFE LOADS (Pounds) FOR JOISTS AND BEAMS LIMITED BY RESISTANCE TO LONGITUDINAL SHEAR (Full Sizes)

TABLE 10

SIZE IN INCHES	SAFE ALLOWABLE LONGITUDINAL SHEAR STRESS IN POUNDS PER SQUARE INCH*																
	50	55	60	65	70	75	80	85	90	95	100	105	110	120	130	140	150
2 × 2	270	290	320	350	370	400	430	450	480	510	530	560	590	640	690	750	800
3	400	440	480	520	560	600	640	680	720	760	800	840	880	960	1,040	1,120	1,200
4	530	590	640	690	750	800	850	910	960	1,010	1,070	1,120	1,170	1,280	1,390	1,490	1,600
6	800	880	960	1,040	1,120	1,200	1,280	1,360	1,440	1,520	1,600	1,680	1,760	1,920	2,080	2,240	2,400
8	1,070	1,170	1,280	1,390	1,490	1,600	1,710	1,810	1,920	2,030	2,130	2,240	2,350	2,560	2,770	2,990	3,200
10	1,330	1,470	1,600	1,730	1,870	2,000	2,130	2,270	2,400	2,530	2,670	2,800	2,930	3,200	3,470	3,730	4,000
12	1,600	1,760	1,920	2,080	2,240	2,400	2,560	2,720	2,880	3,040	3,200	3,360	3,520	3,840	4,160	4,480	4,800
14	1,870	2,050	2,240	2,430	2,610	2,800	2,990	3,170	3,360	3,550	3,730	3,920	4,110	4,480	4,850	5,230	5,600
16	2,130	2,350	2,560	2,770	2,990	3,200	3,410	3,630	3,840	4,050	4,270	4,480	4,690	5,120	5,550	5,970	6,400
3 × 3	600	660	720	780	840	900	960	1,020	1,080	1,140	1,200	1,260	1,320	1,440	1,560	1,680	1,800
4	800	880	960	1,040	1,120	1,200	1,280	1,360	1,440	1,520	1,600	1,680	1,760	1,920	2,080	2,240	2,400
6	1,200	1,320	1,440	1,560	1,680	1,800	1,920	2,040	2,160	2,280	2,400	2,520	2,640	2,880	3,120	3,360	3,600
8	1,600	1,760	1,920	2,080	2,240	2,400	2,560	2,720	2,880	3,040	3,200	3,360	3,520	3,840	4,160	4,480	4,800
10	2,000	2,200	2,400	2,600	2,800	3,000	3,200	3,400	3,600	3,800	4,000	4,200	4,400	4,800	5,200	5,600	6,000
12	2,400	2,640	2,880	3,120	3,360	3,600	3,840	4,080	4,320	4,560	4,800	5,040	5,280	5,760	6,240	6,720	7,200
14	2,800	3,080	3,360	3,640	3,920	4,200	4,480	4,760	5,040	5,320	5,600	5,880	6,160	6,720	7,280	7,840	8,400
16	3,200	3,520	3,840	4,160	4,480	4,800	5,120	5,440	5,760	6,080	6,400	6,720	7,040	7,680	8,320	8,960	9,600
18	3,600	3,960	4,320	4,680	5,040	5,400	5,760	6,120	6,480	6,840	7,200	7,560	7,920	8,640	9,360	10,080	10,800
4 × 4	1,070	1,170	1,280	1,390	1,490	1,600	1,710	1,810	1,920	2,030	2,130	2,240	2,350	2,560	2,770	2,990	3,200
6	1,600	1,760	1,920	2,080	2,240	2,400	2,560	2,720	2,880	3,040	3,200	3,360	3,520	3,840	4,160	4,480	4,800
8	2,130	2,350	2,560	2,770	2,990	3,200	3,410	3,630	3,840	4,050	4,270	4,480	4,690	5,120	5,550	5,970	6,400
10	2,670	2,930	3,200	3,470	3,730	4,000	4,270	4,530	4,800	5,070	5,330	5,600	5,870	6,400	6,930	7,470	8,000
12	3,200	3,520	3,840	4,160	4,480	4,800	5,120	5,440	5,760	6,080	6,400	6,720	7,040	7,680	8,320	8,960	9,600
14	3,730	4,110	4,480	4,850	5,230	5,600	5,970	6,350	6,720	7,090	7,470	7,840	8,210	8,960	9,710	10,450	11,200
16	4,270	4,690	5,120	5,550	5,970	6,400	6,830	7,250	7,680	8,110	8,530	8,960	9,390	10,240	11,090	11,950	12,800
18	4,800	5,280	5,760	6,240	6,720	7,200	7,680	8,160	8,640	9,120	9,600	10,080	10,560	11,520	12,480	13,440	14,400
20	5,330	5,870	6,400	6,930	7,470	8,000	8,530	9,070	9,600	10,130	10,670	11,200	11,730	12,800	13,870	14,930	16,000
6 × 6	2,400	2,640	2,880	3,120	3,360	3,600	3,840	4,080	4,320	4,560	4,800	5,040	5,280	5,760	6,240	6,720	7,200
8	3,200	3,520	3,840	4,160	4,480	4,800	5,120	5,440	5,760	6,080	6,400	6,720	7,040	7,680	8,320	8,960	9,600
10	4,000	4,400	4,800	5,200	5,600	6,000	6,400	6,800	7,200	7,600	8,000	8,400	8,800	9,600	10,400	11,200	12,000
12	4,800	5,280	5,760	6,240	6,720	7,200	7,680	8,160	8,640	9,120	9,600	10,080	10,560	11,520	12,480	13,440	14,400
14	5,600	6,160	6,720	7,280	7,840	8,400	8,960	9,520	10,080	10,640	11,200	11,760	12,320	13,440	14,560	15,680	16,800
16	6,400	7,040	7,680	8,320	8,960	9,600	10,240	10,880	11,520	12,160	12,800	13,440	14,080	15,360	16,640	17,920	19,200
18	7,200	7,920	8,640	9,360	10,080	10,800	11,520	12,240	12,960	13,680	14,400	15,120	15,840	17,280	18,720	20,160	21,600
20	8,000	8,800	9,600	10,400	11,200	12,000	12,800	13,600	14,400	15,200	16,000	16,800	17,600	19,200	20,800	22,400	24,000
8 × 8	4,270	4,690	5,120	5,550	5,970	6,400	6,830	7,250	7,680	8,110	8,530	8,960	9,390	10,240	11,930	11,950	12,800
10	5,330	5,870	6,400	6,930	7,470	8,000	8,530	9,070	9,600	10,130	10,670	11,200	11,730	12,800	13,870	14,930	16,000
12	6,400	7,040	7,680	8,320	8,960	9,600	10,240	10,880	11,520	12,160	12,800	13,440	14,080	15,360	16,640	17,920	19,200
14	7,470	8,210	8,960	9,710	10,450	11,200	11,950	12,690	13,440	14,190	14,930	15,680	16,430	17,920	19,410	20,910	22,400
16	8,530	9,390	10,240	11,090	11,950	12,800	13,650	14,510	15,360	16,210	17,070	12,920	18,770	20,480	22,190	23,890	25,600
18	9,600	10,560	11,520	12,480	13,440	14,400	15,360	16,320	17,280	18,240	19,200	20,160	21,120	23,040	24,960	26,880	28,800
20	10,670	11,730	12,800	13,870	14,930	16,000	17,070	18,130	19,200	20,270	21,330	22,400	23,470	25,600	27,730	29,870	32,000
10 × 10	6,670	7,330	8,000	8,670	9,330	10,000	10,670	11,330	12,000	12,670	13,330	14,000	14,670	16,000	17,330	18,670	20,000
12	8,000	8,800	9,600	10,400	11,200	12,000	12,800	13,600	14,400	15,200	16,000	16,800	17,600	19,200	20,800	22,400	24,000
14	9,330	10,270	11,200	12,130	13,070	14,000	14,930	15,870	16,800	17,730	18,670	19,600	20,530	22,400	24,270	26,130	28,000
16	10,670	11,730	12,800	13,870	14,930	16,000	17,070	18,130	19,200	20,270	21,330	22,400	23,470	25,600	27,730	29,870	32,000
18	12,000	13,200	14,400	15,600	16,800	18,000	19,200	20,400	21,600	22,800	24,000	25,200	26,400	28,800	31,200	33,600	36,000
20	13,330	14,670	16,000	17,330	18,670	20,000	21,330	22,670	24,000	25,330	26,670	28,000	29,330	32,000	34,670	37,330	40,000
12 × 12	9,600	10,560	11,520	12,480	13,440	14,400	15,360	16,320	17,280	18,240	19,200	20,160	21,120	23,040	24,960	26,880	28,800
14	11,200	12,320	13,440	14,560	15,680	16,800	17,920	19,040	20,160	21,280	22,400	23,520	24,640	26,880	29,120	31,360	33,600
16	12,800	14,080	15,360	16,640	17,920	19,200	20,480	21,760	23,040	24,320	25,600	26,880	28,160	30,720	33,280	35,840	38,400
18	14,400	15,840	17,280	18,720	20,160	21,600	23,040	24,480	25,920	27,360	28,800	30,240	31,680	34,560	37,440	40,320	43,200
20	16,000	17,600	19,200	20,800	22,400	24,000	25,600	27,200	28,800	30,400	32,000	33,600	35,200	38,400	41,600	44,800	48,000
14 × 14	13,070	14,370	15,680	16,990	18,290	19,600	20,910	22,210	23,520	24,830	26,130	27,440	28,750	31,360	33,970	36,590	39,200
16	14,930	16,430	17,920	19,410	20,910	22,400	23,890	25,390	26,880	28,370	29,870	31,360	32,850	35,840	38,830	41,810	44,800
18	16,800	18,480	20,160	21,840	23,520	25.200	26,880	28,560	30,240	31,920	33,600	35,280	36,960	40,320	43,680	47,040	50,400
20	18,670	20,530	22,400	24,270	26,130	28,000	29,870	31,730	33,600	35,470	37,330	39,200	41,070	44,800	48,550	52,270	56,000
16 × 16	17,070	18,770	20,480	22,190	23,890	25,600	27,310	29,010	30,720	32,430	34,130	35,840	37,550	40,960	44,370	47,790	51,200
18	19,200	21,120	23,040	24,960	26,880	28,800	30,720	32,640	34,560	36,480	38,400	40,320	42,240	46,080	49,920	53,760	57,600
20	21,330	23,470	25,600	27,730	29,870	32,000	34,130	36,270	38,400	40,530	42,670	44,800	46,930	51,200	55,470	59,730	64,000
18 × 18	21,600	23,760	25,920	28,080	30,240	32,400	34,560	36,720	38,880	41,040	43,200	35,360	47,520	51,840	56,160	60,480	64,800
20	24,000	26,400	28,800	31,200	33,600	36,000	38,400	40,800	43,200	45,600	48,000	50,400	52,800	57,600	62,400	67,200	72,000
20 × 20	26,670	29,330	32,000	34,670	37,330	40,000	42,670	45,330	48,000	50,670	53,330	56,000	58,670	64,000	69,330	74,670	80,000

*For species corresponding to these stresses, see Table 2, Column headed "Longitudinal Shear".

SAFE LOADS (Pounds) FOR JOISTS AND BEAMS LIMITED BY RESISTANCE TO LONGITUDINAL SHEAR (Dressed Sizes)

TABLE 11

SIZE IN INCHES	SAFE ALLOWABLE LONGITUDINAL SHEAR STRESS IN POUNDS PER SQUARE INCH*															
	50	55	60	65	70	75	80	85	90	95	100	105	110	120	130	140
1⅝ × 1⅝	180	190	210	230	250	260	280	300	320	330	350	370	390	420	460	490
2⅝	280	310	340	370	400	430	460	480	510	540	570	600	630	680	740	800
3⅝	340	430	470	510	550	590	630	670	710	750	790	820	860	940	1,020	1,100
5⅝	610	670	730	790	850	910	980	1,040	1,100	1,160	1,220	1,280	1,340	1,460	1,580	1,710
7½	810	890	980	1,060	1,140	1,220	1,300	1,380	1,460	1,540	1,630	1,710	1,790	1,950	2,110	2,280
9½	1,030	1,130	1,240	1,340	1,440	1,540	1,650	1,750	1,850	1,960	2,060	2,160	2,260	2,470	2,680	2,880
11½	1,250	1,370	1,500	1,620	1,740	1,870	1,990	2,120	2,240	2,370	2,490	2,620	2,740	2,990	3,240	3,490
13½	1,460	1,610	1,760	1,900	2,050	2,190	2,340	2,490	2,630	2,780	2,930	3,070	3,220	3,510	3,800	4,100
15½	1,680	1,850	2,020	2,180	2,350	2,520	2,690	2,860	3,020	3,190	3,360	3,530	3,690	4,030	4,370	4,700
2⅝ × 2⅝	460	510	550	600	640	690	740	780	830	370	920	970	1,010	1,100	1,190	1,290
3⅝	630	700	760	830	890	950	1,020	1,080	1,140	1,210	1,270	1,330	1,400	1,520	1,650	1,780
5⅝	980	1,080	1,180	1,280	1,380	1,480	1,580	1,670	1,770	1,870	1,970	2,070	2,170	2,360	2,560	2,760
7½	1,310	1,440	1,580	1,710	1,840	1,970	2,100	2,230	2,360	2,490	2,630	2,760	2,890	3,150	3,410	3,680
9½	1,660	1,830	2,000	2,160	2,330	2,490	2,660	2,830	2,990	3,160	3,330	3,490	3,660	3,990	4,320	4,660
11½	2,010	2,210	2,420	2,620	2,820	3,020	3,220	3,420	3,630	3,820	4,030	4,230	4,430	4,830	5,230	5,640
13½	2,360	2,600	2,840	3,070	3,310	3,540	3,780	4,020	4,250	4,490	4,730	4,960	5,200	5,670	6,140	6,620
15½	2,710	2,980	3,260	3,530	3,800	4,070	4,340	4,610	4,880	5,150	5,430	5,700	5,970	6,510	7,050	7,600
17½	3,060	3,370	3,680	3,980	4,290	4,590	4,900	5,210	5,510	5,820	6,130	6,430	6,740	7,350	7,960	8,580
3⅝ × 3⅝	880	960	1,050	1,140	1,230	1,310	1,400	1,490	1,580	1,660	1,750	1,840	1,930	2,100	2,280	2,450
5⅝	1,360	1,500	1,630	1,770	1,900	2,040	2,180	2,310	2,450	2,580	2,720	2,860	2,990	3,260	3,530	3,810
7½	1,810	2,000	2,180	2,360	2,540	2,720	2,900	3,080	3,260	3,440	3,630	3,810	3,990	4,350	4,710	5,080
9½	2,300	2,530	2,760	2,990	3,210	3,440	3,670	3,900	4,130	4,360	4,590	4,820	5,050	5,510	5,970	6,430
11½	2,780	3,060	3,340	3,610	3,890	4,170	4,450	4,730	5,000	5,280	5,560	5,840	6,110	6,670	7,230	7,780
13½	3,260	3,590	3,920	4,240	4,570	4,890	5,220	5,550	5,870	6,200	6,530	6,850	7,180	7,830	8,480	9,140
15½	3,750	4,120	4,500	4,870	5,240	5,620	5,990	6,370	6,740	7,120	7,490	7,870	8,240	8,990	9,740	10,490
17½	4,230	4,650	5,080	5,500	5,920	6,340	6,770	7,190	7,610	8,040	8,460	8,880	9,300	10,150	11,000	11,840
19½	4,710	5,180	5,660	6,130	6,600	7,070	7,540	8,010	8,480	8,950	9,430	9,900	10,370	11,310	12,250	13,200
5½ × 5½	2,020	2,220	2,420	2,620	2,820	3,030	3,230	3,430	3,630	3,830	4,030	4,240	4,440	4,840	5,240	5,650
7½	2,750	3,030	3,300	3,580	3,850	4,130	4,400	4,680	4,950	5,230	5,500	5,780	6,050	6,600	7,150	7,700
9½	3,480	3,830	4,180	4,530	4,880	5,230	5,570	5,920	6,270	6,620	6,970	7,320	7,660	8,360	9,060	9,750
11½	4,220	4,640	5,060	5,480	5,900	6,330	6,750	7,170	7,590	8,010	8,430	8,860	9,280	10,120	10,960	11,810
13½	4,950	5,450	5,940	6,440	6,930	7,430	7,920	8,420	8,910	9,410	9,900	10,400	10,890	11,880	12,870	13,860
15½	5,680	6,250	6,820	7,390	7,960	8,530	9,090	9,660	10,230	10,800	11,370	11,940	12,500	13,640	14,780	15,910
17½	6,420	7,060	7,700	8,340	8,980	9,630	10,270	10,910	11,550	12,190	12,830	13,480	14,120	15,400	16,680	17,970
19½	7,150	7,870	8,580	9,300	10,010	10,730	11,440	12,160	12,870	13,590	14,300	15,020	15,730	17,160	18,590	20,020
7½ × 7½	3,750	4,130	4,500	4,880	5,250	5,630	6,000	6,380	6,750	7,130	7,500	7,880	8,250	9,000	9,750	10,500
9½	4,750	5,230	5,700	6,180	6,650	7,130	7,600	8,080	8,550	9,030	9,500	9,980	10,450	11,400	12,350	13,300
11½	5,750	6,330	6,900	7,480	8,050	8,630	9,200	9,780	10,350	10,930	11,500	12,080	12,650	13,800	14,950	16,100
13½	6,750	7,430	8,100	8,780	9,450	10,130	10,800	11,480	12,150	12,830	13,500	14,180	14,850	16,200	17,550	18,900
15½	7,750	8,530	9,300	10,080	10,850	11,630	12,400	13,180	13,950	14,730	15,500	16,280	17.050	18,600	20,150	21,700
17½	8,750	9,630	10,500	11,380	12,250	13,130	14,000	14,880	15,750	16,630	17,500	18,380	19,250	21,000	22,750	24,500
19½	9,750	10,730	11,700	12,680	13,650	14,630	15,600	16,580	17,550	18,530	19,500	20,480	21,450	23,400	25,350	27,300
9½ × 9½	6,020	6,620	7,220	7,820	8,420	9,030	9,630	10,230	10,830	11,430	12,030	12,640	13,240	14,440	15,640	16,850
11½	7,280	8,010	8,740	9,470	10,200	10,930	11,650	12,380	13,110	13,840	14,570	15,300	16,020	17,480	18,940	20,390
13½	8,550	9,410	10,260	11,120	11,970	12,830	13,680	14,540	15,390	16,250	17,100	17,960	18,810	20,520	22,230	23,940
15½	9,820	10,800	11,780	12,760	13,740	14,730	15,710	16,690	17,670	18,650	19,630	20,620	21,600	23,560	25,520	27,490
17½	11,080	12,190	13,300	14,410	15,520	16,630	17,730	18,840	19,950	21,060	22,170	23,280	24,380	26,600	28,820	31,030
19½	12,350	13,590	14,820	16,060	17,290	18,530	19,760	21,000	22,230	23,470	24,700	25,940	27,170	29,640	32,110	34,570
11½ × 11½	8,820	9,700	10,580	11,460	12,340	13,230	14,110	14,990	15,870	16,750	17,630	18,520	19,400	21,160	22,920	24,690
13½	10,350	11,390	12,420	13,460	14,490	15,530	16,560	17,600	18,630	19,670	20,700	21,740	22,770	24,840	26,910	28,980
15½	11,880	13,070	14,260	15,450	16,640	17,830	19,010	20,200	21,390	22,580	23,770	24,960	26,140	28,520	30,900	33,270
17½	13,420	14,760	16,100	17,440	18,780	20,130	21,470	22,810	24,150	25,490	26,830	28,180	29,520	32,200	34,880	37,570
19½	14,950	16,450	17,940	19,440	20,930	22,430	23,920	25,420	26,910	28,410	29,900	31,400	32,890	35,880	38,870	41,860
13½ × 13½	12,150	13,370	14,580	15,800	17,010	18,230	19,440	20,660	21,870	23,090	24,300	25,520	26,730	29,160	31,590	34,020
15½	13,950	15,350	16,740	18,140	19,530	20,930	22,320	23,720	25,110	26,510	27,900	29,300	30,690	33,480	36,270	39,060
17½	15,750	17,330	18,900	20,480	22,050	23,630	25,200	26,780	28,350	29,930	31,500	33,080	34,650	37,800	40,950	44,100
19½	17,550	19,310	21,060	22,820	24,570	26,330	28,080	29,840	31,590	33,350	35,100	36,860	38,610	42,120	45,630	49,140
15½ × 15½	16,020	17,620	19,220	20,820	22,420	24,030	25,630	27,230	28,830	30,430	32,030	33,640	35,240	38,440	41,640	44,850
17½	18,080	19,890	21,700	23,510	25,320	27,130	28,930	30,740	32,550	34,360	36,170	37,980	39,780	43,400	47,020	50,630
19½	20,150	22,170	24,180	26,200	28,210	30,230	32,240	34,260	36,270	38,290	40,300	42,320	44,330	48,360	52,390	56,420
17½ × 17½	20,420	22,460	24,500	26,540	28,580	30,630	32,670	34,710	36,750	38,790	40,830	42,880	44,920	49,000	53,080	57,170
19½	22,750	25,030	27,300	29,580	31,850	34,130	36,400	38,680	40,950	43,230	45,500	47,780	50,050	54,600	59,150	63,700
19½ × 19½	25,350	27,890	30,420	32,960	35,490	38,030	40,560	43,100	45,630	48,170	50,700	53,240	55,770	60,840	65,910	70,980

*For species corresponding to these stresses, see Table 2, Column headed "Longitudinal Shear".

DEFLECTIONS FOR JOISTS AND BEAMS (Full Sizes) IN INCHES*

TABLE 12

SIZE IN INCHES	MODULUS OF ELASTICITY (pounds per square inch)								MOMENT OF INERTIA
	800,000	1,000,000	1,100,000	1,200,000	1,300,000	1,400,000	1,500,000	1,600,000	
2 × 4	.00263590	.00210872	.00191697	.00175727	.00162212	.00150619	.00140582	.00131795	10.67
6	.00078125	.00062500	.00056817	.00052083	.00048078	.00044642	.00041667	.00039063	36.00
8	.00032960	.00026368	.00023970	.00021973	.00020283	.00018834	.00017579	.00016480	85.33
10	.00016875	.00013500	.00012272	.00011250	.00010385	.00009643	.00009000	.00008438	166.67
12	.00009765	.00007812	.00007102	.00006510	.00006009	.00005580	.00005208	.00004883	288.00
14	.00006150	.00004920	.00004472	.00004100	.00003785	.00003514	.00003280	.00003075	457.33
16	.00004120	.00003296	.00002996	.00002747	.00002535	.00002354	.00002197	.00002060	682.67
3 × 3	.00416667	.00333333	.00303022	.00277778	.00256415	.00238089	.00222222	.00208333	6.75
4	.00175781	.00140625	.00127838	.00117188	.00108175	.00100444	.00093750	.00087891	16.00
6	.00052083	.00041667	.00037878	.00034722	.00032052	.00029761	.00027778	.00026042	54.00
8	.00021973	.00017578	.00015980	.00014648	.00013522	.00012556	.00011719	.00010986	128.00
10	.00011250	.00009000	.00008182	.00007500	.00006923	.00006428	.00006000	.00005625	250.00
12	.00006510	.00005208	.00004735	.00004340	.00004006	.00003720	.00003472	.00003255	432.00
14	.00004100	.00003280	.00002982	.00002733	.00002523	.00002343	.00002187	.00002050	686.00
16	.00002747	.00002197	.00001997	.00001831	.00001690	.00001569	.00001465	.00001373	1,024.00
18	.00001929	.00001543	.00001403	.00001286	.00001187	.00001102	.00001029	.00000965	1,458.00
4 × 4	.00131856	.00105485	.00095892	.00087904	.00081143	.00075344	.00070323	.00065928	21.33
6	.00039063	.00031250	.00028408	.00026042	.00024039	.00022321	.00020833	.00019531	72.00
8	.00016479	.00013183	.00011985	.00010986	.00010141	.00009417	.00008789	.00008240	170.67
10	.00008438	.00006750	.00006136	.00005625	.00005192	.00004821	.00004500	.00004219	333.33
12	.00004883	.00003906	.00003551	.00003255	.00003005	.00002790	.00002604	.00002441	576.00
14	.00003075	.00002460	.00002236	.00002050	.00001892	.00001757	.00001640	.00001537	914.67
16	.00002060	.00001648	.00001498	.00001373	.00001268	.00001177	.00001099	.00001030	1,365.33
18	.00001447	.00001157	.00001052	.00000965	.00000890	.00000827	.00000772	.00000723	1,944.00
20	.00001056	.00000844	.00000767	.00000703	.00000649	.00000603	.00000563	.00000527	2,666.67
6 × 6	.00026042	.00020833	.00018939	.00017361	.00016026	.00014881	.00013889	.00013020	108.00
8	.00010986	.00008789	.00007990	.00007324	.00006761	.00006278	.00005859	.00005493	256.00
10	.00005625	.00004500	.00004091	.00003750	.00003462	.00003214	.00003000	.00002813	500.00
12	.00003255	.00002604	.00002367	.00002170	.00002003	.00001860	.00001736	.00001628	864.00
14	.00002050	.00001640	.00001491	.00001367	.00001262	.00001171	.00001093	.00001025	1,372.00
16	.00001373	.00001099	.00000999	.00000916	.00000845	.00000785	.00000732	.00000687	2,048.00
18	.00000965	.00000772	.00000701	.00000643	.00000594	.00000551	.00000514	.00000482	2,916.00
20	.00000703	.00000563	.00000511	.00000469	.00000433	.00000402	.00000375	.00000352	4,000.00
8 × 8	.00008240	.00006592	.00005992	.00005493	.00005071	.00004708	.00004395	.00004120	341.33
10	.00004219	.00003375	.00003068	.00002813	.00002596	.00002411	.00002250	.00002109	666.67
12	.00002441	.00001953	.00001776	.00001628	.00001502	.00001395	.00001302	.00001221	1,152.00
14	.00001538	.00001230	.00001118	.00001025	.00000946	.00000879	.00000820	.00000769	1,829.33
16	.00001030	.00000824	.00000749	.00000687	.00000634	.00000589	.00000549	.00000515	2,730.67
18	.00000723	.00000579	.00000526	.00000482	.00000445	.00000413	.00000386	.00000362	3,888.00
20	.00000527	.00000422	.00000384	.00000352	.00000325	.00000301	.00000281	.00000264	5,333.33
10 × 10	.00003375	.00002700	.00002454	.00002250	.00002077	.00001929	.00001800	.00001688	833.33
12	.00001953	.00001563	.00001420	.00001302	.00001202	.00001116	.00001042	.00000977	1,440.00
14	.00001230	.00000984	.00000894	.00000820	.00000757	.00000703	.00000656	.00000615	2,286.67
16	.00000824	.00000659	.00000599	.00000549	.00000507	.00000471	.00000440	.00000412	3,413.33
18	.00000579	.00000463	.00000421	.00000386	.00000356	.00000331	.00000309	.00000289	4,860.00
20	.00000422	.00000338	.00000307	.00000281	.00000260	.00000241	.00000225	.00000211	6,666.67
12 × 12	.00001628	.00001302	.00001184	.00001085	.00001002	.00000930	.00000868	.00000814	1,728.00
14	.00001025	.00000880	.00000745	.00000683	.00000631	.00000586	.00000547	.00000512	2,744.00
16	.00000687	.00000549	.00000499	.00000458	.00000423	.00000392	.00000366	.00000343	4,096.00
18	.00000482	.00000386	.00000351	.00000322	.00000297	.00000276	.00000257	.00000241	5,832.00
20	.00000352	.00000281	.00000256	.00000234	.00000216	.00000201	.00000188	.00000176	8,000.00
14 × 14	.00000879	.00000703	.00000639	.00000586	.00000541	.00000502	.00000469	.00000439	3,201.33
16	.00000589	.00000471	.00000428	.00000392	.00000362	.00000336	.00000314	.00000294	4,778.67
18	.00000413	.00000331	.00000301	.00000276	.00000254	.00000236	.00000220	.00000207	6,804.00
20	.00000301	.00000241	.00000219	.00000201	.00000185	.00000172	.00000161	.00000151	9,333.33
16 × 16	.00000515	.00000412	.00000375	.00000343	.00000317	.00000294	.00000275	.00000257	5,461.33
18	.00000362	.00000289	.00000263	.00000241	.00000223	.00000207	.00000193	.00000181	7,776.00
20	.00000264	.00000211	.00000192	.00000176	.00000162	.00000151	.00000141	.00000132	10,666.67
18 × 18	.00000322	.00000257	.00000234	.00000214	.00000198	.00000184	.00000171	.00000161	8,748.00
20	.00000234	.00000188	.00000170	.00000156	.00000144	.00000134	.00000125	.00000117	12,000.00
20 × 20	.00000211	.00000169	.00000153	.00000141	.00000130	.00000121	.00000113	.00000105	13,333.33

*The values given in this table are the deflections in inches when carrying a uniformly distributed load of 1,000 pounds over a span of one foot. (For calculating deflections for other loads and spans see instructions in the introduction of this Appendix.)

TABLE 13

DEFLECTIONS FOR JOISTS AND BEAMS (Dressed Sizes) IN INCHES*

SIZE IN INCHES	MODULUS OF ELASTICITY (pounds per square inch)								MOMENT OF INERTIA
	800,000	1,000,000	1,100,000	1,200,000	1,300,000	1,400,000	1,500,000	1,600,000	
1 5/8 × 3 5/8	.00436010	.00348808	.00317098	.00290673	.00268314	.00249149	.00232539	.00218005	6.45
5 5/8	.00116695	.00093356	.00084869	.00077797	.00071812	.00066683	.00062237	.00058348	24.10
7 1/2	.00049231	.00039385	.00035804	.00032821	.00030296	.00028132	.00026256	.00024615	57.13
9 1/2	.00024224	.00019379	.00017618	.00016150	.00014907	.00013842	.00012920	.00012112	116.10
11 1/2	.00013656	.00010925	.00009932	.00009104	.00008404	.00007804	.00007283	.00006828	205.95
13 1/2	.00008442	.00006753	.00006139	.00005628	.00005195	.00004824	.00004502	.00004221	333.18
15 1/2	.00005577	.00004462	.00004056	.00003718	.00003432	.00003187	.00002975	.00002789	504.27
2 5/8 × 2 5/8	.00710815	.00568652	.00516956	.00473877	.00437425	.00406180	.00379101	.00355408	3.96
3 5/8	.00269911	.00215929	.00196299	.00179941	.00166099	.00154235	.00143953	.00134956	10.42
5 5/8	.00072240	.00057792	.00052538	.00048160	.00044455	.00041280	.00038528	.00036120	38.93
7 1/2	.00030476	.00024381	.00022165	.00020318	.00018755	.00017415	.00016254	.00015238	92.29
9 1/2	.00014996	.00011997	.00010906	.00009997	.00009228	.00008569	.00007998	.00007498	187.55
11 1/2	.00008455	.00006763	.00006148	.00005636	.00005202	.00004831	.00004509	.00004227	332.69
13 1/2	.00005226	.00004181	.00003801	.00003484	.00003216	.00002986	.00002787	.00002613	538.21
15 1/2	.00003453	.00002762	.00002511	.00002302	.00002125	.00001973	.00001841	.00001726	814.60
17 1/2	.00002399	.00001919	.00001745	.00001599	.00001476	.00001371	.00001280	.00001200	1,172.36
3 5/8 × 3 5/8	.00195453	.00156362	.00142147	.00130302	.00120279	.00111687	.00104241	.00097726	14.39
5 5/8	.00052312	.00041849	.00038045	.00034874	.00032192	.00029892	.00027900	.00026156	53.76
7 1/2	.00022069	.00017655	.00016050	.00014713	.00013581	.00012611	.00011770	.00011035	127.44
9 1/2	.00010859	.00008687	.00007898	.00007239	.00006683	.00006205	.00005792	.00005430	259.00
11 1/2	.00006122	.00004897	.00004452	.00004081	.00003767	.00003498	.00003265	.00003061	459.43
13 1/2	.00003784	.00003027	.00002752	.00002523	.00002329	.00002162	.00002018	.00001892	743.24
15 1/2	.00002500	.00002000	.00001818	.00001667	.00001539	.00001429	.00001333	.00001250	1,124.92
17 1/2	.00001737	.00001390	.00001263	.00001158	.00001069	.00000993	.00000927	.00000869	1,618.98
19 1/2	.00001256	.00001005	.00000913	.00000837	.00000773	.00000718	.00000670	.00000628	2,239.91
5 1/2 × 5 1/2	.00036883	.00029506	.00026824	.00024589	.00022697	.00021076	.00019671	.00018441	76.25
7 1/2	.00014546	.00011636	.00010579	.00009697	.00008951	.00008312	.00007758	.00007273	193.35
9 1/2	.00007157	.00005726	.00005205	.00004771	.00004404	.00004090	.00003817	.00003579	392.93
11 1/2	.00004035	.00003228	.00002934	.00002690	.00002483	.00002306	.00002152	.00002017	697.02
13 1/2	.00002494	.00001995	.00001814	.00001663	.00001535	.00001425	.00001330	.00001247	1,127.59
15 1/2	.00001648	.00001318	.00001198	.00001099	.00001014	.00000942	.00000879	.00000824	1,706.65
17 1/2	.00001145	.00000916	.00000833	.00000763	.00000705	.00000654	.00000611	.00000573	2,456.20
19 1/2	.00000828	.00000662	.00000602	.00000552	.00000509	.00000473	.00000441	.00000414	3,398.24
7 1/2 × 7 1/2	.00010667	.00008533	.00007758	.00007111	.00006564	.00006095	.00005689	.00005333	263.67
9 1/2	.00005249	.00004199	.00003817	.00003499	.00003230	.00002999	.00002799	.00002624	535.86
11 1/2	.00002959	.00002367	.00002152	.00001973	.00001821	.00001691	.00001578	.00001479	950.55
13 1/2	.00001829	.00001463	.00001330	.00001219	.00001126	.00001045	.00000976	.00000915	1,537.73
15 1/2	.00001208	.00000967	.00000879	.00000806	.00000744	.00000691	.00000645	.00000604	2,327.42
17 1/2	.00000840	.00000672	.00000611	.00000560	.00000517	.00000480	.00000448	.00000420	3,349.61
19 1/2	.00000607	.00000486	.00000441	.00000405	.00000374	.00000347	.00000324	.00000303	4,634.30
9 1/2 × 9 1/2	.00004144	.00003315	.00003014	.00002762	.00002550	.00002368	.00002210	.00002072	678.78
11 1/2	.00002336	.00001869	.00001699	.00001557	.00001438	.00001335	.00001246	.00001168	1,204.08
13 1/2	.00001444	.00001155	.00001050	.00000963	.00000889	.00000825	.00000770	.00000722	1,947.88
15 1/2	.00000954	.00000763	.00000694	.00000636	.00000587	.00000545	.00000509	.00000477	2,948.19
17 1/2	.00000663	.00000530	.00000482	.00000442	.00000408	.00000379	.00000354	.00000331	4,243.02
19 1/2	.00000479	.00000383	.00000349	.00000319	.00000295	.00000274	.00000256	.00000240	5,870.36
11 1/2 × 11 1/2	.00001930	.00001547	.00001403	.00001286	.00001188	.00001103	.00001029	.00000965	1,457.50
13 1/2	.00001193	.00000954	.00000868	.00000795	.00000734	.00000682	.00000636	.00000596	2,357.85
15 1/2	.00000788	.00000631	.00000573	.00000525	.00000485	.00000450	.00000420	.00000394	3,568.70
17 1/2	.00000548	.00000438	.00000398	.00000365	.00000337	.00000313	.00000292	.00000274	5,136.05
19 1/2	.00000396	.00000317	.00000288	.00000264	.00000244	.00000226	.00000211	.00000198	7,105.90
13 1/2 × 13 1/2	.00001016	.00000813	.00000739	.00000677	.00000625	.00000581	.00000542	.00000508	2,767.92
15 1/2	.00000671	.00000537	.00000488	.00000448	.00000413	.00000384	.00000358	.00000336	4,189.36
17 1/2	.00000467	.00000373	.00000339	.00000311	.00000287	.00000267	.00000249	.00000233	6,029.30
19 1/2	.00000337	.00000270	.00000245	.00000225	.00000208	.00000193	.00000180	.00000169	8,341.73
15 1/2 × 15 1/2	.00000585	.00000468	.00000425	.00000390	.00000360	.00000334	.00000312	.00000292	4,810.13
17 1/2	.00000406	.00000325	.00000296	.00000271	.00000250	.00000232	.00000217	.00000203	6,922.70
19 1/2	.00000294	.00000235	.00000214	.00000196	.00000181	.00000168	.00000157	.00000147	9,577.79
17 1/2 × 17 1/2	.00000360	.00000288	.00000262	.00000240	.00000221	.00000206	.00000192	.00000180	7,815.58
19 1/2	.00000260	.00000208	.00000189	.00000173	.00000160	.00000149	.00000139	.00000130	10,813.11
19 1/2 × 19 1/2	.00000233	.00000187	.00000170	.00000156	.00000144	.00000133	.00000125	.00000117	12,049.17

*The values given in this table are the deflections in inches when carrying a uniformly distributed load of 1,000 pounds over a span of one foot. (For calculating deflections for other loads and spans see instructions in the introduction of this Appendix.)

SAFE LOADS FOR TIMBER COLUMNS, FULL SIZES, CONTINUOUSLY DRY, IN POUNDS

SELECT STRUCTURAL GRADE (Canadian Standards Association)

TABLE 14

	COLUMN SIZE IN INCHES	CROSS-SECTIONAL AREA IN SQUARE INCHES	HEIGHT IN FEET	RATIO OF LENGTH TO LEAST DIMENSION	EASTERN CEDAR	W. CEDAR — W. WH. PINE — WHITE PINE — PONDEROSA PINE — LODGEPOLE PINE	EASTERN HEMLOCK — AMABILIS FIR — JACK PINE	EASTERN SPRUCE — SITKA SPRUCE — ENGELMANN SPRUCE — RED PINE
1	6 × 6	36.0	8	16.0	20,160	26,280	27,000	27,000
2			10	20.0	17,640	23,040	24,120	24,840
3			12	24.0	13,680	17,280	18,720	20,520
4			14	28.0	10,080	12,600	14,040	15,120
5			16	32.0	8,640	11,160	12,240	13,320
6			18	36.0	6,480	7,920	9,000	9,720
7			20	40.0	5,040	6,120	6,840	7,560
8	8 × 8	64.0	8	12.0	37,760	49,920	49,920	50,560
9			10	15.0	35,840	46,720	48,000	48,000
10			12	18.0	33,920	44,160	45,440	46,720
11			14	21.0	28,160	35,840	39,040	40,320
12			16	24.0	24,320	30,720	33,280	36,480
13			18	27.0	17,920	22,400	24,960	26,880
14			20	30.0	15,360	19,840	21,760	23,680
15	10 × 10	100.0	8	9.6	60,000	80,000	80,000	80,000
16			10	12.0	59,000	78,000	78,000	79,000
17			12	14.4	57,000	76,000	77,000	77,000
18			14	16.8	56,000	73,000	75,000	75,000
19			16	19.2	49,000	64,000	67,000	69,000
20			18	21.6	44,000	56,000	61,000	63,000
21			20	24.0	38,000	48,000	52,000	57,000
22	12 × 12	144.0	8	8.0	86,400	115,200	115,200	115,200
23			10	10.0	86,400	115,200	115,200	115,200
24			12	12.0	84,960	112,320	112,320	113,760
25			14	14.0	82,080	109,440	110,880	110,880
26			16	16.0	80,640	105,120	108,000	108,000
27			18	18.0	76,320	99,360	102,240	105,120
28			20	20.0	70,560	92,160	96,480	99,360
29	14 × 14	196.0	8	6.9	117,600	156,800	156,800	156,800
30			10	8.6	117,600	156,800	156,800	156,800
31			12	10.3	117,600	156,800	156,800	156,800
32			14	12.0	115,640	152,880	152,880	154,840
33			16	13.7	111,720	148,960	150,920	150,920
34			18	15.4	109,760	143,080	147,000	147,000
35			20	17.1	103,880	135,240	139,160	143,080
36	16 × 16	256.0	8	6.0	153,600	204,800	204,800	204,800
37			10	7.5	153,600	204,800	204,800	204,800
38			12	9.0	153,600	204,800	204,800	204,800
39			14	10.5	153,600	204,800	204,800	204,800
40			16	12.0	151,040	199,680	199,680	202,240
41			18	13.5	145,920	194,560	197,120	197,120
42			20	15.0	143,360	186,880	192,000	192,000
43	18 × 18	324.0	8	5.3	194,400	259,200	259,200	259,200
44			10	6.7	194,400	259,200	259,200	259,200
45			12	8.0	194,400	259,200	259,200	259,200
46			14	9.3	194,400	259,200	259,200	259,200
47			16	10.7	194,400	259,200	259,200	259,200
48			18	12.0	191,160	252,720	252,720	255,960
49			20	13.3	184,680	246,240	249,480	249,480
50	20 × 20	400.0	8	4.8	240,000	320,000	320,000	320,000
51			10	6.0	240,000	320,000	320,000	320,000
52			12	7.2	240,000	320,000	320,000	320,000
53			14	8.4	240,000	320,000	320,000	320,000
54			16	9.6	240,000	320,000	320,000	320,000
55			18	10.8	240,000	320,000	320,000	320,000
56			20	12.0	236,000	312,000	312,000	316,000

SAFE LOADS FOR TIMBER COLUMNS, FULL SIZES, CONTINUOUSLY DRY, IN POUNDS

SELECT STRUCTURAL GRADE (Canadian Standards Association)

LARCH (TAMARACK)	MOUNTAIN DOUGLAS FIR — WESTERN HEMLOCK	WESTERN LARCH	COAST DOUGLAS FIR	COAST DOUGLAS FIR (DENSE)	WHITE ELM	RED OAK — WHITE OAK	BEECH — YELLOW BIRCH — HARD MAPLE	
33,120	33,480	39,600	39,960	45,360	29,880	36,720	42,840	1
29,160	30,240	34,200	35,640	38,160	26,640	32,760	37,080	2
22,320	24,120	25,560	27,360	27,360	20,520	25,560	27,360	3
16,560	17,640	18,720	29,160	20,160	15,120	18,720	20,160	4
14,400	15,480	16,560	17,640	17,640	13,320	16,560	17,640	5
10,440	11,160	12,240	12,960	12,960	9,720	12,240	12,960	6
7,920	8,640	9,360	9,720	9,720	7,560	9,360	9,720	7
62,720	62,720	74,880	74,880	87,040	56,320	69,120	80,640	8
58,880	59,520	70,400	71,040	80,640	53,120	65,280	76,160	9
56,320	56,960	66,560	67,840	74,880	50,560	62,720	71,680	10
46,080	48,640	53,760	56,960	58,240	42,880	52,480	57,600	11
39,680	42,880	45,440	48,640	48,640	36,480	45,440	48,640	12
29,440	31,360	33,280	35,840	35,840	26,880	33,280	35,840	13
25,600	27,520	29,440	31,360	31,360	23,680	29,440	31,360	14
100,000	100,000	120,000	120,000	140,000	90,000	110,000	130,000	15
98,000	98,000	117,000	117,000	136,000	88,000	108,000	126,000	16
96,000	96,000	114,000	115,000	132,000	86,000	105,000	124,000	17
92,000	93,000	111,000	111,000	126,000	83,000	102,000	119,000	18
81,000	84,000	95,000	99,000	106,000	74,000	91,000	103,000	19
72,000	76,000	84,000	89,000	91,000	67,000	82,000	90,000	20
62,000	67,000	71,000	76,000	76,000	57,000	71,000	76,000	21
144,000	144,000	172,800	172,800	201,600	129,600	158,400	187,200	22
144,000	144,000	172,800	172,800	201,600	129,600	158,400	187,200	23
141,120	141,120	168,480	168,480	195,840	126,720	155,520	181,440	24
138,240	138,240	164,160	165,600	190,080	123,840	151,200	178,560	25
132,480	133,920	158,400	159,840	181,440	119,520	146,880	171,360	26
126,720	128,160	149,760	152,640	168,480	113,760	141,120	161,280	27
116,840	120,960	136,800	142,560	152,640	106,560	131,040	148,320	28
196,000	196,000	235,200	235,200	274,400	176,400	215,600	254,800	29
196,000	196,000	235,200	235,200	274,400	176,400	215,600	254,800	30
196,000	196,000	235,200	235,200	274,400	176,400	215,600	254,800	31
192,080	192,080	229,320	229,320	266,560	172,480	211,680	246,960	32
188,160	188,160	223,440	225,400	258,720	168,560	205,800	243,040	33
180,320	182,280	215,600	217,560	246,960	162,680	199,920	233,240	34
172,480	174,440	203,840	207,760	229,320	154,840	192,080	219,520	35
256,000	256,000	307,200	307,200	358,400	230,400	281,600	332,800	36
256,000	256,000	307,200	307,200	358,400	230,400	281,600	332,800	37
256,000	256,000	307,200	307,200	358,400	230,400	281,600	332,800	38
256,000	256,000	307,200	307,200	358,400	230,400	281,600	332,800	39
250,880	250,880	299,520	299,520	348,160	225,280	276,480	322,560	40
245,760	245,760	291,840	294,400	337,920	220,160	268,800	317,440	41
235,520	238,080	281,600	284,160	322,560	212,480	261,120	304,640	42
324,000	324,000	388,800	388,800	453,600	291,600	356,400	421,200	43
324,000	324,000	388,800	388,800	453,600	291,600	356,400	421,200	44
324,000	324,000	388,800	388,800	453,600	291,600	356,400	421,200	45
324,000	324,000	388,800	388,800	453,600	291,600	356,400	421,200	46
324,000	324,000	388,800	388,800	453,600	291,600	356,400	421,200	47
317,520	317,520	379,080	379,080	440,640	285,120	349,920	408,240	48
311,040	311,040	369,360	372,600	427,680	278,640	340,200	401,760	49
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	50
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	51
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	52
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	53
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	54
400,000	400,000	480,000	480,000	560,000	360,000	440,000	520,000	55
392,000	392,000	468,000	468,000	544,000	352,000	432,000	504,000	56

TABLE **14**

SAFE LOADS FOR TIMBER COLUMNS, FULL SIZES, CONTINUOUSLY DRY, IN POUNDS

STRUCTURAL GRADE (Canadian Standards Association)

	COLUMN SIZE IN INCHES	CROSS-SECTIONAL AREA IN SQUARE INCHES	HEIGHT IN FEET	RATIO OF LENGTH TO LEAST DIMENSION	EASTERN CEDAR	W. CEDAR — W. WH. PINE — WHITE PINE — PONDEROSA PINE — LODGEPOLE PINE	EASTERN HEMLOCK — AMABILIS FIR — JACK PINE	EASTERN SPRUCE — SITKA SPRUCE — ENGELMANN SPRUCE — RED PINE
1	6 × 6	36.0	8	16.0	16,560	21,960	21,960	22,320
2			10	20.0	15,480	20,160	20,510	20,880
3			12	24.0	13,320	16,920	18,000	18,720
4			14	28.0	10,080	12,600	13,680	15,120
5			16	32.0	8,640	10,800	12,240	13,320
6			18	36.0	6,480	7,920	9,000	9,720
7			20	40.0	5,040	6,120	6,840	7,560
8	8 × 8	64.0	8	12.0	30,080	40,320	40,320	40,320
9			10	15.0	29,440	39,040	39,040	39,680
10			12	18.0	28,160	37,760	38,400	38,400
11			14	21.0	25,600	33,280	34,560	35,840
12			16	24.0	23,680	30,080	32,000	33,280
13			18	27.0	17,920	22,400	24,320	26,880
14			20	30.0	15,360	19,200	21,760	23,680
15	10 × 10	100.0	8	9.6	48,000	64,000	64,000	64,000
16			10	12.0	47,000	63,000	63,000	63,000
17			12	14.4	47,000	62,000	62,000	63,000
18			14	16.8	46,000	61,000	61,000	62,000
19			16	19.2	43,000	56,000	57,000	58,000
20			18	21.6	40,000	52,000	54,000	56,000
21			20	24.0	37,000	47,000	50,000	52,000
22	12 × 12	144.0	8	8.0	69,120	92,160	92,160	92,160
23			10	10.0	69,120	92,160	92,160	92,160
24			12	12.0	67,680	90,720	90,720	90,720
25			14	14.0	67,680	89,280	89,280	90,720
26			16	16.0	66,240	87,840	87,840	89,280
27			18	18.0	63,370	84,960	86,400	86,400
28			20	20.0	61,920	80,640	82,080	83,520
29	14 × 14	196.0	8	6.9	94,080	125,440	125,440	125,440
30			10	8.6	94,080	125,440	125,440	125,440
31			12	10.3	94,080	125,440	125,440	125,440
32			14	12.0	92,120	123,480	123,480	123,480
33			16	13.7	92,120	121,520	121,520	123,480
34			18	15.4	90,160	119,560	119,560	121,520
35			20	17.1	86,240	115,640	117,600	117,600
36	16 × 16	256.0	8	6.0	122,880	163,840	163,840	163,840
37			10	7.5	122,880	163,840	163,840	163,840
38			12	9.0	122,880	163,840	163,840	163,840
39			14	10.5	122,880	163,840	163,840	163,840
40			16	12.0	120,320	161,280	161,280	161,280
41			18	13.5	120,320	158,720	158,720	161,280
42			20	15.0	117,760	156,160	156,160	158,720
43	18 × 18	324.0	8	5.3	155,520	207,360	207,360	207,360
44			10	6.7	155,520	207,360	207,360	207,360
45			12	8.0	155,520	207,360	207,360	207,360
46			14	9.3	155,520	207,360	207,360	207,360
47			16	10.7	155,520	207,360	207,360	207,360
48			18	12.0	152,280	204,120	204,120	204,120
49			20	13.3	152,280	200,880	200,880	204,120
50	20 × 20	400.0	8	4.8	192,000	256,000	256,000	256,000
51			10	6.0	192,000	256,000	256,000	256,000
52			12	7.2	192,000	256,000	256,000	256,000
53			14	8.4	192,000	256,000	256,000	256,000
54			16	9.6	192,000	256,000	256,000	256,000
55			18	10.8	192,000	256,000	256,000	256,000
56			20	12.0	188,000	252,000	252,000	252,000

SAFE LOADS FOR TIMBER COLUMNS, FULL SIZES, CONTINUOUSLY DRY, IN POUNDS

STRUCTURAL GRADE (Canadian Standards Association)

LARCH (TAMARACK)	MOUNTAIN DOUGLAS FIR / WESTERN HEMLOCK	WESTERN LARCH	COAST DOUGLAS FIR	COAST DOUGLAS FIR (DENSE)	WHITE ELM	RED OAK / WHITE OAK	BEECH / YELLOW BIRCH / HARD MAPLE	
27,360	27,720	32,760	33,120	37,800	24,840	30,240	35,280	1
25,200	25,920	30,240	30,600	34,200	23,040	28,080	32,400	2
21,600	22,680	25,200	26,280	27,360	19,800	24,480	27,000	3
16,200	17,640	18,720	20,160	20,160	15,120	18,720	20,160	4
14,400	15,480	16,560	17,640	17,640	13,320	16,560	17,640	5
10,440	11,160	12,240	12,960	12,960	9,720	12,240	12,960	6
7,920	8,640	9,360	9,720	9,720	7,560	9,360	9,720	7
50,560	50,560	60,160	60,800	70,400	45,440	55,680	65,280	8
48,640	49,280	58,240	58,880	67,200	44,160	53,760	62,720	9
47,360	48,000	56,320	56,960	64,640	42,880	52,480	60,800	10
42,240	43,520	49,920	51,200	55,680	38,400	47,360	53,760	11
38,400	40,320	44,800	46,720	48,640	35,200	43,520	48,000	12
28,800	31,360	33,280	35,840	35,840	26,880	33,280	35,840	13
25,600	27,520	29,440	31,360	31,360	23,680	29,440	31,360	14
80,000	80,000	96,000	96,000	112,000	72,000	88,000	104,000	15
79,000	79,000	94,000	95,000	110,000	71,000	87,000	102,000	16
78,000	78,000	93,000	93,000	108,000	70,000	86,000	101,000	17
76,000	77,000	91,000	92,000	105,000	69,000	84,000	98,000	18
70,000	72,000	84,000	85,000	95,000	64,000	78,000	90,000	19
66,000	68,000	78,000	80,000	87,000	60,000	74,000	84,000	20
60,000	63,000	70,000	73,000	76,000	55,000	68,000	75,000	21
115,200	115,200	138,240	138,240	161,280	103,680	126,720	149,760	22
115,200	115,200	138,240	138,240	161,280	103,680	126,720	149,760	23
113,760	113,760	135,360	136,800	158,400	102,240	125,280	146,880	24
112,320	112,320	133,920	133,920	155,520	100,800	123,840	145,440	25
109,440	110,880	131,040	132,480	151,200	99,360	120,960	141,120	26
106,560	108,000	126,720	128,160	145,440	96,480	118,080	136,800	27
100,800	103,680	120,960	122,400	136,800	92,160	112,320	129,600	28
156,800	156,800	188,160	188,160	219,520	141,120	172,480	203,840	29
156,800	156,800	188,160	188,160	219,520	141,120	172,480	203,840	30
156,800	156,800	188,160	188,160	219,520	141,120	172,480	203,840	31
154,840	154,840	184,240	186,200	215,600	139,160	170,520	199,920	32
152,880	152,880	182,280	182,280	211,680	137,200	168,560	197,960	33
148,960	150,920	178,360	180,320	205,800	135,240	164,640	192,080	34
145,040	147,000	172,480	174,440	197,960	131,320	160,720	186,200	35
204,800	204,800	245,760	245,760	286,720	184,320	225,280	266,240	36
204,800	204,800	245,760	245,760	286,720	184,320	225,280	266,240	37
204,800	204,800	245,760	245,760	286,720	184,320	225,280	266,240	38
204,800	204,800	245,760	245,760	286,720	184,320	225,280	266,240	39
202,240	202,240	240,640	243,200	281,600	181,760	222,720	261,120	40
199,680	199,680	238,080	238,080	276,480	179,200	220,160	258,560	41
194,560	197,120	232,960	235,520	268,800	176,640	215,040	250,880	42
259,200	259,200	311,040	311,040	362,880	233,280	285,120	336,960	43
259,200	259,200	311,040	311,040	362,880	233,280	285,120	336,960	44
259,200	259,200	311,040	311,040	362,880	233,280	285,120	336,960	45
259,200	259,200	311,040	311,040	362,880	233,280	285,120	336,960	46
259,200	259,200	311,040	311,040	362,880	233,280	285,120	336,960	47
255,960	255,960	304,560	307,800	356,400	230,040	281,880	330,480	48
252,720	252,720	301,320	301,320	349,920	226,800	278,640	327,240	49
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	50
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	51
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	52
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	53
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	54
320,000	320,000	384,000	384,000	448,000	288,000	352,000	416,000	55
316,000	316,000	376,000	380,000	440,000	284,000	348,000	408,000	56

SAFE LOADS FOR TIMBER COLUMNS, DRESSED SIZES, CONTINUOUSLY DRY, IN POUNDS

SELECT STRUCTURAL GRADE (Canadian Standards Association)

TABLE 15

	COLUMN SIZE IN INCHES	CROSS-SECTIONAL AREA IN SQUARE INCHES	HEIGHT IN FEET	RATIO OF LENGTH TO LEAST DIMENSION	EASTERN CEDAR	W. CEDAR — W. WH. PINE — WHITE PINE — PONDEROSA PINE — LODGEPOLE PINE	EASTERN HEMLOCK — AMABILIS FIR — JACK PINE	EASTERN SPRUCE — SITKA SPRUCE — ENGELMANN SPRUCE — RED PINE
1	5½ × 5½	30.25	8	17.46	16,033	20,873	21,478	22,083
2			10	21.82	13,310	16,940	18,453	19,058
3			12	26.18	9,983	12,403	13,613	14,823
4			14	30.55	7,260	9,378	10,285	11,193
5			16	34.91	5,445	6,655	7,563	8,168
6			18	39.27	4,235	5,143	5,748	6,353
7			20	43.64	3,328	4,235	4,538	4,840
8	7½ × 7½	56.25	8	12.80	33,188	43,875	43,875	44,438
9			10	16.00	31,500	41,063	42,188	42,188
10			12	19.20	27,563	36,000	37,688	38,813
11			14	22.40	24,750	31,500	34,313	35,438
12			16	25.60	18,563	23,063	25,313	27,563
13			18	28.80	15,750	19,688	21,938	23,625
14			20	32.00	13,500	17,438	19,125	20,813
15	9½ × 9½	90.25	8	10.11	54,150	72,200	72,200	72,200
16			10	12.63	53,248	70,395	70,395	71,298
17			12	15.16	50,540	65,883	67,688	67,688
18			14	17.68	47,833	62,273	64,078	65,883
19			16	20.21	44,223	57,760	60,468	62,273
20			18	22.74	39,710	50,540	55,053	56,858
21			20	25.26	29,783	37,003	40,613	44,223
22	11½ × 11½	132.25	8	8.35	79,350	105,800	105,800	105,800
23			10	10.43	79,350	105,800	105,800	105,800
24			12	12.52	78,028	103,155	103,155	104,478
25			14	14.61	75,383	100,510	101,833	101,833
26			16	16.70	74,060	96,543	99,188	99,188
27			18	18.78	70,093	91,253	93,898	96,543
28			20	20.87	64,803	84,640	88,608	91,253
29	13½ × 13½	182.25	8	7.11	109,350	145,800	145,800	145,800
30			10	8.89	109,350	145,800	145,800	145,800
31			12	10.67	109,350	145,800	145,800	145,800
32			14	12.44	107,528	142,155	142,155	143,978
33			16	14.22	103,883	138,510	140,333	140,333
34			18	16.00	102,060	133,043	136,688	136,688
35			20	17.78	96,593	125,753	129,398	133,043
36	15½ × 15½	240.25	8	6.19	144,150	192,200	192,200	192,200
37			10	7.74	144,150	192,200	192,200	192,200
38			12	9.29	144,150	192,200	192,200	192,200
39			14	10.84	144,150	192,200	192,200	192,200
40			16	12.39	141,748	187,395	187,395	189,798
41			18	13.94	136,943	182,590	184,993	184,993
42			20	15.48	134,540	175,383	180,188	180,188
43	17½ × 17½	306.25	8	5.49	183,750	245,000	245,000	245,000
44			10	6.86	183,750	245,000	245,000	245,000
45			12	8.23	183,750	245,000	245,000	245,000
46			14	9.60	183,750	245,000	245,000	245,000
47			16	10.97	183,750	245,000	245,000	245,000
48			18	12.34	180,688	238,875	238,875	241,938
49			20	13.71	174,563	232,750	235,813	235,813
50	19½ × 19½	380.25	8	4.92	228,150	304,200	304,200	304,200
51			10	6.15	228,150	304,200	304,200	304,200
52			12	7.38	228,150	304,200	304,200	304,200
53			14	8.62	228,150	304,200	304,200	304,200
54			16	9.85	228,150	304,200	304,200	304,200
55			18	11.08	224,348	296,595	296,595	300,398
56			20	12.31	224,348	296,595	296,595	300,398

SAFE LOADS FOR TIMBER COLUMNS, DRESSED SIZES, CONTINUOUSLY DRY, IN POUNDS

SELECT STRUCTURAL GRADE (Canadian Standards Association)

LARCH (TAMARACK)	MOUNTAIN DOUGLAS FIR — WESTERN HEMLOCK	WESTERN LARCH	COAST DOUGLAS FIR	COAST DOUGLAS FIR (DENSE)	WHITE ELM	RED OAK — WHITE OAK	BEECH — YELLOW BIRCH — HARD MAPLE	
26,620	26,923	31,460	32,065	35,393	23,898	29,645	33,880	1
21,780	22,990	25,410	26,923	27,528	20,268	24,805	27,225	2
16,033	17,243	18,453	19,663	19,663	14,823	18,453	19,663	3
12,100	13,008	13,915	14,823	14,823	11,193	13,195	14,823	4
8,773	9,378	10,285	10,890	10,890	8,168	10,285	10,890	5
6,655	7,260	7,865	8,168	8,168	6,353	7,865	8,168	6
5,445	5,748	6,050	6,655	6,655	4,840	6,050	6,655	7
55,125	55,125	65,813	65,813	76,500	49,500	60,750	70,875	8
51,750	52,313	61,875	62,438	70,875	46,688	57,375	66,938	9
45,563	47,250	53,438	55,688	59,625	41,625	51,188	57,938	10
40,500	42,750	47,250	50,063	51,188	37,688	46,125	50,625	11
29,813	32,063	34,313	36,563	36,563	27,563	34,313	36,563	12
25,875	27,563	29,250	31,500	31,500	23,625	29,250	31,500	13
22,500	24,188	25,875	27,563	27,563	20,813	25,875	27,563	14
90,250	90,250	108,300	108,300	126,350	81,225	99,275	117,325	15
88,445	88,455	105,593	105,593	122,740	79,420	97,470	113,715	16
83,030	83,933	99,275	100,178	113,715	74,908	92,055	107,398	17
79,420	80,323	93,860	95,665	105,593	71,298	88,445	101,080	18
73,103	75,810	85,738	89,348	95,665	66,785	82,128	92,958	19
64,980	68,590	75,810	80,323	82,128	60,468	74,005	81,225	20
47,833	51,443	55,053	58,663	58,663	44,223	55,053	58,663	21
132,250	132,250	158,700	158,700	185,150	119,025	145,475	171,925	22
132,250	132,250	158,700	158,700	185,150	119,025	145,475	171,925	23
129,605	129,605	154,733	154,733	179,860	116,380	142,830	166,635	24
126,960	126,960	150,765	152,088	174,570	113,735	138,863	163,990	25
121,670	122,993	145,475	146,798	166,635	109,768	134,895	157,378	26
116,380	117,703	137,540	140,185	154,733	104,478	129,605	148,120	27
107,123	111,090	125,638	130,928	140,185	97,865	120,348	136,218	28
182,250	182,250	218,700	218,700	255,150	164,025	200,475	236,925	29
182,250	182,250	218,700	218,700	255,150	164,025	200,475	236,925	30
182,250	182,250	218,700	218,700	255,150	164,025	200,475	236,925	31
178,605	178,605	213,233	213,233	247,860	160,380	196,830	229,635	32
174,960	174,960	207,765	209,588	240,570	156,735	191,363	225,990	33
167,670	169,493	200,475	202,298	229,635	151,268	185,895	216,878	34
160,380	162,203	189,540	193,185	213,233	143,978	178,605	204,120	35
240,250	240,250	288,300	288,300	336,350	216,225	264,275	312,325	36
240,250	240,250	288,300	288,300	336,350	216,225	264,275	312,325	37
240,250	240,250	288,300	288,300	336,350	216,225	264,275	312,325	38
240,250	240,250	288,300	288,300	336,350	216,225	264,275	312,325	39
235,445	235,445	281,093	281,093	326,740	211,420	259,470	302,715	40
230,640	230,640	273,885	276,288	317,130	206,615	252,263	297,910	41
221,030	223,433	264,275	266,678	302,715	199,408	245,055	285,898	42
306,250	306,250	367,500	367,500	428,750	275,625	336,875	398,125	43
306,250	306,250	367,500	367,500	428,750	275,625	336,875	398,125	44
306,250	306,250	367,500	367,500	428,750	275,625	336,875	398,125	45
306,250	306,250	367,500	367,500	428,750	275,625	336,875	398,125	46
306,250	306,250	367,500	367,500	428,750	275,625	336,875	398,125	47
300,125	300,125	358,313	358,313	416,500	269,500	330,750	385,875	48
294,000	294,000	349,125	352,188	404,250	263,375	321,563	379,750	49
380,250	380,250	456,300	456,300	532,350	342,225	418,275	494,325	50
380,250	380,250	456,300	456,300	532,350	342,225	418,275	494,325	51
380,250	380,250	456,300	456,300	532,350	342,225	418,275	494,325	52
380,250	380,250	456,300	456,300	532,350	342,225	418,275	494,325	53
380,250	380,250	456,300	456,300	532,350	342,225	418,275	494,325	54
372,645	372,645	444,893	444,893	517,140	334,620	410,670	479,115	55
372,645	372,645	444,893	444,893	517,140	334,620	410,670	479,115	56

SAFE LOADS IN POUNDS FOR TIMBER COLUMNS, DRESSED SIZES, CONTINUOUSLY DRY

STRUCTURAL GRADE (Canadian Standards Association)

TABLE 15

	COLUMN SIZE IN INCHES	CROSS-SECTIONAL AREA IN SQUARE INCHES	HEIGHT IN FEET	RATIO OF LENGTH TO LEAST DIMENSION	EASTERN CEDAR	W. CEDAR — W. WH. PINE — WHITE PINE — PONDEROSA PINE — LODGEPOLE PINE	EASTERN HEMLOCK — AMABILIS FIR — JACK PINE	EASTERN SPRUCE — SITKA SPRUCE — ENGELMANN SPRUCE — RED PINE
1	5½ × 5½	30.25	8	17.46	13,310	17,848	18,150	18,150
2			10	21.82	12,100	15,730	16,335	16,940
3			12	26.18	9,680	12,403	13,310	14,520
4			14	30.55	7,260	9,075	10,285	11,193
5			16	34.91	5,445	6,655	7,563	8,168
6			18	39.27	4,235	5,143	5,748	6,353
7			20	43.64	3,328	4,235	4,538	4,840
8	7½ × 7½	56.25	8	12.80	26,438	35,438	35,438	35,438
9			10	16.00	25,875	34,313	34,313	34,875
10			12	19.20	24,188	31,500	32,063	32,625
11			14	22.40	22,500	29,250	30,375	31,500
12			16	25.60	18,000	23,063	24,750	27,000
13			18	28.80	15,750	19,688	21,375	23,625
14			20	32.00	13,500	16,875	19,125	20,813
15	9½ × 9½	90.25	8	10.11	43,320	57,760	57,760	57,760
16			10	12.63	42,418	56,858	56,858	56,858
17			12	15.16	41,515	55,053	55,053	55,955
18			14	17.68	39,710	53,248	54,150	54,150
19			16	20.21	38,808	50,540	51,443	52,345
20			18	22.74	36,100	46,930	48,735	50,540
21			20	25.26	28,880	37,003	39,710	43,320
22	11½ × 11½	132.25	8	8.35	63,480	84,640	84,640	84,640
23			10	10.43	63,480	84,640	84,640	84,640
24			12	12.52	62,158	83,318	83,318	83,318
25			14	14.61	62,158	81,995	81,995	83,318
26			16	16.70	60,835	80,673	80,673	81,995
27			18	18.78	58,190	78,028	79,350	79,350
28			20	20.87	56,868	74,060	75,383	76,705
29	13½ × 13½	182.25	8	7.11	87,480	116,640	116,640	116,640
30			10	8.89	87,480	116,640	116,640	116,640
31			12	10.67	87,480	116,640	116,640	116,640
32			14	12.44	85,658	114,818	114,818	114,818
33			16	14.22	85,658	112,995	112,995	114,818
34			18	16.00	83,835	111,173	111,173	112,995
35			20	17.78	80,190	107,528	109,350	109,350
36	15½ × 15½	240.25	8	6.19	115,320	153,760	153,760	153,760
37			10	7.74	115,320	153,760	153,760	153,760
38			12	9.29	115,320	153,760	153,760	153,760
39			14	10.84	115,320	153,760	153,760	153,760
40			16	12.39	112,918	151,358	151,358	151,358
41			18	13.94	112,918	148,955	148,955	151,358
42			20	15.48	110,515	146,553	146,553	148,955
43	17½ × 17½	306.25	8	5.49	147,000	196,000	196,000	196,000
44			10	6.86	147,000	196,000	196,000	196,000
45			12	8.23	147,000	196,000	196,000	196,000
46			14	9.60	147,000	196,000	196,000	196,000
47			16	10.97	147,000	196,000	196,000	196,000
48			18	12.34	143,938	192,938	192,938	192,938
49			20	13.71	143,938	189,875	189,875	192,938
50	19½ × 19½	380.25	8	4.92	182,520	243,360	243,360	243,360
51			10	6.15	182,520	243,360	243,360	243,360
52			12	7.38	182,520	243,360	243,360	243,360
53			14	8.62	182,520	243,360	243,360	243,360
54			16	9.85	182,520	243,360	243,360	243,360
55			18	11.08	178,718	239,558	239,558	239,558
56			20	12.31	178,718	239,558	239,558	239,558

SAFE LOADS IN POUNDS FOR TIMBER COLUMNS, DRESSED SIZES, CONTINUOUSLY DRY

STRUCTURAL GRADE (Canadian Standards Association)

LARCH (TAMARACK)	MOUNTAIN DOUGLAS FIR — WESTERN HEMLOCK	WESTERN LARCH	COAST DOUGLAS FIR	COAST DOUGLAS FIR (DENSE)	WHITE ELM	RED OAK — WHITE OAK	BEECH — YELLOW BIRCH — HARD MAPLE	
22,385	22,688	26,620	26,923	30,553	20,268	24,805	28,738	1
19,965	20,570	23,595	24,200	26,318	18,150	22,385	25,410	2
16,033	16,940	18,453	19,663	19,663	14,520	18,150	19,663	3
12,100	13,008	13,915	14,823	14,823	11,193	13,915	14,823	4
8,773	9,378	10,285	10,890	10,890	8,168	10,285	10,890	5
6,655	7,260	7,865	8,168	8,168	6,353	7,865	8,168	6
5,445	5,748	6,050	6,655	6,655	4,840	6,050	6,655	7
44,438	44,438	52,875	53,438	61,875	39,938	48,938	57,375	8
42,750	43,313	51,188	51,750	59,063	38,813	47,250	55,125	9
39,375	40,500	47,250	47,813	53,438	36,000	43,875	50,625	10
37,125	38,250	43,875	45,000	48,938	33,750	41,625	47,250	11
29,813	31,500	34,313	36,563	36,563	27,000	33,750	36,563	12
25,313	27,563	29,250	31,500	31,500	23,625	29,250	31,500	13
22,500	24,188	25,875	27,563	27,563	20,813	25,875	27,563	14
72,200	72,200	86,640	86,640	101,080	64,980	79,420	93,860	15
71,298	71,298	84,835	85,738	99,275	64,078	78,518	92,055	16
68,590	69,493	82,128	83,030	94,763	62,273	75,810	88,445	17
66,785	67,688	79,420	80,323	91,153	60,468	74,005	85,738	18
63,175	64,980	75,810	76,713	85,738	57,760	70,395	81,225	19
59,565	61,370	70,395	72,200	78,518	54,150	66,785	75,810	20
47,833	50,540	55,053	58,663	58,663	43,320	54,150	58,663	21
105,800	105,800	126,960	126,960	148,120	95,220	116,380	137,540	22
105,800	105,800	126,960	126,960	148,120	95,220	116,380	137,540	23
104,478	104,478	124,315	125,638	145,475	93,898	115,058	134,895	24
103,155	103,155	122,993	122,993	142,830	92,575	113,735	133,573	25
100,510	101,833	120,348	121,670	138,863	91,253	111,090	129,605	26
97,865	99,188	116,380	117,703	133,573	88,608	108,445	125,638	27
92,575	95,220	111,090	112,413	125,638	84,640	103,155	119,025	28
145,800	145,800	174,960	174,960	204,120	131,220	160,380	189,540	29
145,800	145,800	174,960	174,960	204,120	131,220	160,380	189,540	30
145,800	145,800	174,960	174,960	204,120	131,220	160,380	189,540	31
143,978	143,978	171,315	173,138	200,475	129,398	158,558	185,895	32
142,155	142,155	169,493	169,493	196,830	127,575	156,735	184,073	33
138,510	140,333	165,848	167,670	191,363	125,753	153,090	178,605	34
134,865	136,688	160,380	162,203	184,073	122,108	149,445	173,138	35
192,200	192,200	230,640	230,640	269,080	172,980	211,420	249,860	36
192,200	192,200	230,640	230,640	269,080	172,980	211,420	249,860	37
192,200	192,200	230,640	230,640	269,080	172,980	211,420	249,860	38
192,200	192,200	230,640	230,640	269,080	172,980	211,420	249,860	39
189,798	189,798	225,835	228,238	264,275	170,578	209,018	245,055	40
187,395	187,395	223,433	223,433	259,470	168,175	206,615	242,653	41
182,590	184,993	218,628	221,030	252,263	165,773	201,810	235,445	42
245,000	245,000	294,000	294,000	343,000	220,500	269,500	318,500	43
245,000	245,000	294,000	294,000	343,000	220,500	269,500	318,500	44
245,000	245,000	294,000	294,000	343,000	220,500	269,500	318,500	45
245,000	245,000	294,000	294,000	343,000	220,500	269,500	318,500	46
245,000	245,000	294,000	294,000	343,000	220,500	269,500	318,500	47
241,938	241,938	287,875	290,938	336,875	217,438	266,438	312,375	48
238,875	238,875	284,813	284,813	330,750	214,375	263,375	209,313	49
304,200	304,200	365,040	365,040	425,880	273,780	334,620	395,460	50
304,200	304,200	365,040	365,040	425,880	273,780	334,620	395,460	51
304,200	304,200	365,040	365,040	425,880	273,780	334,620	395,460	52
304,200	304,200	365,040	365,040	425,880	273,780	334,620	395,460	53
304,200	304,200	365,040	365,040	425,880	273,780	334,620	395,460	54
300,398	300,398	357,435	361,238	418,275	269,978	330,818	387,855	55
300,398	300,398	357,435	361,238	418,275	269,978	330,818	387,855	56

SIZES OF FLOOR JOISTS FOR 12-INCH AND 16-INCH SPACING* FOR VARIOUS FLOOR LOADS

TABLE 16

	FULL SIZE		DRESSED SIZE	
	Size in inches	bd^2	Size in inches	bd^2
1	2 × 4	32	1⅝ × 3⅝	21.35
2	6	72	5⅝	51.42
3	8	128	7½	91.41
4	10	200	9½	146.66
5	12	288	11½	214.91
6	14	392	13½	296.16
7	16	512	15½	390.41
8	3 × 6	108	2⅝ × 5⅝	83.06
9	8	192	7½	147.66
10	10	300	9½	236.91
11	12	432	11½	347.16
12	14	588	13½	478.41
13	16	768	15½	630.66
14	4 × 6	144	3⅝ × 5⅝	114.70
15	8	256	7½	203.91
16	10	400	9½	327.16
17	12	576	11½	479.41
18	14	784	13½	660.66
19	16	1,024	15½	870.91
20	18	1,296	17½	1,110.16
21	20	1,600	19½	1,378.41

SPAN IN FEET	LOAD ON FLOOR (Pounds per square foot) 30		40		50		60		70	
	DISTANCE BETWEEN CENTRES OF JOISTS (inches) 12″	16″	12″	16″	12″	16″	12″	16″	12″	16″
8	17,280	23,040	23,040	30,720	28,800	38,400	34,560	46,080	40,320	53,760
9	21,870	29,160	29,160	38,880	36,450	48,600	43,740	58,320	51,030	68,040
10	27,000	36,000	36,000	48,000	45,000	60,000	54,000	72,000	63,000	84,000
11	32,670	43,560	43,560	58,080	54,450	72,600	65,340	87,120	76,230	101,640
12	38,880	51,840	51,840	69,120	64,800	86,400	77,760	103,680	90,720	120,960
13	45,630	60,840	60,840	81,120	76,050	101,400	91,260	121,680	106,470	141,960
14	52,920	70,560	70,560	94,080	88,200	117,600	105,840	141,120	123,480	164,640
15	60,750	81,000	81,000	108,000	101,250	135,000	121,500	162,000	141,750	189,000
16	69,120	92,160	92,160	122,880	115,200	153,600	138,240	184,320	161,280	215,040
17	70,030	104,040	104,040	138,720	130,050	173,400	156,060	208,080	182,070	242,760
18	87,480	116,640	116,640	155,520	145,800	194,400	174,960	233,280	204,120	272,160
19	97,470	129,960	129,960	173,280	162,450	216,600	194,940	259,920	227,430	303,240
20	108,000	144,000	144,000	192,000	180,000	240,000	216,000	288,000	252,000	336,000
21	119,070	158,760	158,760	211,680	198,450	264,600	238,140	317,520	277,830	370,440
22	130,680	174,240	174,240	232,320	217,800	290,400	261,360	348,480	304,920	406,560
23	142,830	190,440	190,440	253,920	238,050	317,400	285,660	380,880	333,270	444,360
24	155,520	207,360	207,360	276,480	259,200	345,600	311,040	414,720	362,880	483,840
25	168,750	225,000	225,000	300,000	281,250	375,000	337,500	450,000	393,750	525,000

*For calculating sizes of joists from values given in this table, see instructions given in the explanation of tables in this Appendix.

SIZES OF FLOOR JOISTS FOR 12-INCH AND 16-INCH SPACING* FOR VARIOUS FLOOR LOADS

LOAD ON FLOOR (Pounds per square foot)															
80		90		100		110		120		130		140		150	
DISTANCE BETWEEN CENTRES OF JOISTS (inches)															
12″	16″	12″	16″	12″	16″	12″	16″	12″	16″	12″	16″	12″	16″	12″	16″
46,080	61,440	51,840	69,120	57,600	76,800	63,360	84,480	69,120	92,160	74,880	99,840	80,640	107,520	86,400	115,200
58,320	77,760	65,610	87,480	72,900	97,200	80,190	106,920	87,480	116,640	94,770	126,360	102,060	136,080	109,350	145,800
72,000	96,000	81,000	108,000	90,000	120,000	99,000	132,000	108,000	144,000	117,000	156,000	126,000	168,000	135,000	180,000
87,120	116,160	98,010	130,680	108,900	145,200	119,790	159,720	130,680	174,240	141,570	188,760	152,460	203,280	163,350	217,800
103,680	138,240	116,640	155,520	129,600	172,800	142,560	190,080	155,520	207,360	168,480	224,640	181,440	241,920	194,400	259,200
121,680	162,240	136,890	182,520	152,100	202,800	167,310	223,080	182,520	243,360	197,730	263,640	212,940	283,920	228,150	304,200
141,120	188,160	158,760	211,680	176,400	235,200	194,040	258,720	211,680	282,240	229,320	305,760	246,960	329,280	264,600	352,800
162,000	216,000	182,250	243,000	202,500	270,000	222,750	297,000	243,000	324,000	263,250	351,000	283,500	378,000	303,750	405,000
184,320	245,760	207,360	276,480	230,400	307,200	253,440	337,920	276,480	368,640	299,520	399,360	322,560	430,080	345,600	460,800
208,080	277,440	234,090	312,120	260,100	346,800	286,110	381,480	312,120	416,160	338,130	450,840	364,140	485,520	390,150	520,200
233,280	311,040	262,440	349,920	291,600	388,800	320,760	427,680	349,920	466,560	379,080	505,440	408,240	544,320	437,400	583,200
259,920	346,560	292,410	389,880	324,900	433,200	357,390	476,520	389,880	519,840	422,370	563,160	454,860	606,480	487,350	649,800
288,000	384,000	324,000	432,000	360,000	480,000	396,000	528,000	432,000	576,000	468,000	624,000	504,000	672,000	540,000	720,000
317,520	423,360	357,210	476,280	396,900	529,200	436,590	582,120	476,280	635,040	515,970	687,960	555,660	740,880	595,350	793,800
348,480	464,640	392,040	522,720	435,600	580,800	479,160	638,880	522,720	696,960	566,280	755,040	609,840	813,120	653,400	871,200
380,880	507,840	428,490	571,320	476,100	634,800	523,710	698,280	571,320	761,760	618,930	825,240	666,540	888,720	714,150	952,200
414,720	552,960	466,560	622,080	518,400	691,200	570,240	760,320	622,080	829,440	673,920	898,560	725,760	967,680	777,600	1,036,800
450,000	600,000	506,250	675,000	562,500	750,000	618,750	825,000	675,000	900,000	731,250	975,000	787,500	1,050,000	843,750	1,125,000

*For calculating sizes of joists from values given in this table, see instructions given in the explanation of tables in this Appendix.

TABLE 17

MOMENTS OF INERTIA AND SECTION MODULI FOR TIMBERS *(Full and Dressed Sizes)*

Full Size	Dressed Size	Area of Cross-section		Moment of Inertia, $I=\frac{bd^3}{12}$		Section Modulus, $S=\frac{bd^2}{6}$	
		Full Size in Square Inches	Dressed Size in Square Inches	Full Size	Dressed Size	Full Size	Dressed Size
2 × 2	1⅝ × 1⅝	4	2.64	1.33	0.58	1.33	0.72
2 × 3	1⅝ × 2⅝	6	4.27	4.50	2.45	3.00	1.87
2 × 4	1⅝ × 3⅝	8	5.89	10.67	6.45	5.33	3.56
2 × 6	1⅝ × 5⅝	12	9.14	38.00	24.10	12.00	8.57
2 × 8	1⅝ × 7½	16	12.19	85.33	57.13	21.33	15.23
2 × 10	1⅝ × 9½	20	15.44	166.67	116.10	33.33	24.44
2 × 12	1⅝ × 11½	24	18.69	288.00	205.95	48.00	35.82
2 × 14	1⅝ × 13½	28	21.94	457.33	333.18	65.33	49.36
2 × 16	1⅝ × 15½	32	25.19	682.57	504.27	85.33	65.07
3 × 3	2⅝ × 2⅝	9	6.89	6.75	3.96	4.50	3.01
3 × 4	2⅝ × 3⅝	12	9.52	16.00	10.42	8.00	5.75
3 × 6	2⅝ × 5⅝	18	14.77	54.00	38.93	18.00	13.84
3 × 8	2⅝ × 7½	24	19.69	128.00	92.29	32.00	24.61
3 × 10	2⅝ × 9½	30	24.94	250.00	187.55	50.00	39.48
3 × 12	2⅝ × 11½	36	30.19	432.00	332.69	72.00	57.86
3 × 14	2⅝ × 13½	42	35.44	686.00	538.21	98.00	79.73
3 × 16	2⅝ × 15½	48	40.69	1,024.00	814.60	128.00	105.11
3 × 18	2⅝ × 17½	54	45.94	1,458.00	1,172.36	162.00	133.98
4 × 4	3⅝ × 3⅝	16	13.14	21.33	14.39	10.67	7.94
4 × 6	3⅝ × 5⅝	24	20.39	72.00	53.76	24.00	19.12
4 × 8	3⅝ × 7½	32	27.19	170.67	127.44	42.67	33.98
4 × 10	3⅝ × 9½	40	34.44	333.33	259.00	66.67	54.53
4 × 12	3⅝ × 11½	48	41.69	576.00	459.43	96.00	79.90
4 × 14	3⅝ × 13½	56	48.94	914.67	743.24	130.67	110.11
4 × 16	3⅝ × 15½	64	56.19	1,365.33	1,124.92	170.67	145.15
4 × 18	3⅝ × 17½	72	63.44	1,944.00	1,618.98	216.00	185.03
4 × 20	3⅝ × 19½	80	70.69	2,666.67	2,239.91	266.67	229.73
6 × 6	5½ × 5½	36	30.25	108.00	76.25	36.00	27.73
6 × 8	5½ × 7½	48	41.25	256.00	193.35	64.00	51.56
6 × 10	5½ × 9½	60	52.25	500.00	392.93	100.00	82.73
6 × 12	5½ × 11½	72	63.25	864.00	697.02	144.00	121.23
6 × 14	5½ × 13½	84	74.25	1,372.00	1,127.59	198.00	167.07
6 × 16	5½ × 15½	96	85.25	2,048.00	1,706.65	256.00	220.24
6 × 18	5½ × 17½	108	96.25	2,916.00	2,456.20	324.00	280.74
6 × 20	5½ × 19½	120	107.25	4,000.00	3,398.24	400.00	348.58
8 × 8	7½ × 7½	64	56.25	341.33	263.67	85.33	70.31
8 × 10	7½ × 9½	80	71.25	666.67	535.86	133.33	112.81
8 × 12	7½ × 11½	96	86.25	1,152.00	950.55	192.00	165.31
8 × 14	7½ × 13½	112	101.25	1,829.33	1,537.73	261.33	227.81
8 × 16	7½ × 15½	160	147.25	3,413.33	2,948.19	426.67	300.31
8 × 18	7½ × 17½	180	166.25	4,860.00	4,243.02	540.00	382.81
8 × 20	7½ × 19½	200	185.25	6,666.67	5,870.36	666.67	475.31
10 × 10	9½ × 9½	128	116.25	2,730.67	2,327.42	341.33	142.89
10 × 12	9½ × 11½	144	131.25	3,888.00	3,349.61	432.00	209.39
10 × 14	9½ × 13½	160	146.25	5,333.33	4,634.30	533.33	288.56
10 × 16	9½ × 15½	100	90.25	833.33	678.78	166.67	380.39
10 × 18	9½ × 17½	120	109.25	1,440.00	1,204.08	240.00	484.89
10 × 20	9½ × 19½	140	128.25	2,286.67	1,947.88	326.67	602.05
12 × 12	11½ × 11½	144	132.25	1,728.00	1,457.50	288.00	253.48
12 × 14	11½ × 13½	168	155.25	2,744.00	2,357.85	392.00	349.32
12 × 16	11½ × 15½	192	178.25	4,096.00	3,568.70	512.00	460.49
12 × 18	11½ × 17½	216	201.25	5,832.00	5,136.05	648.00	586.99
12 × 20	11½ × 19½	240	224.25	8,000.00	7,105.90	800.00	728.83
14 × 14	13½ × 13½	196	182.25	3,201.33	2,767.92	457.33	410.06
14 × 16	13½ × 15½	224	209.25	4,778.67	4,189.36	597.33	540.56
14 × 18	13½ × 17½	252	236.25	6,804.00	6,029.30	756.00	689.06
14 × 20	13½ × 19½	280	263.25	9,333.33	8,341.73	933.33	855.56
16 × 16	15½ × 15½	256	240.25	5,461.33	4,810.13	682.67	620.64
16 × 18	15½ × 17½	288	271.25	7,776.00	6,922.70	864.00	791.14
16 × 20	15½ × 19½	320	302.25	10,666.67	9,577.79	1,066.67	982.30
18 × 18	17½ × 17½	324	306.25	8,748.58	7,815.58	972.00	893.24
18 × 20	17½ × 19½	360	341.25	12,000.00	10,813.11	1,200.00	1,109.08
20 × 20	19½ × 19½	400	380.25	13,333.33	12,049.17	1,333.33	1,235.81

SAFE WORKING STRESSES FOR GREEN, CLEAR, WOOD OF SPECIES GROWN IN CANADA*

TABLE 18

SPECIES	BENDING (pounds per square inch)			COMPRESSION (pounds per square inch)	
	STRESS AT EXTREME FIBRE	MODULUS OF ELASTICITY	LONGITUDINAL SHEAR	PERPENDICULAR TO GRAIN	PARALLEL TO GRAIN (Short Columns)
Cedar, Eastern White	1100	800,000	100	130	750
Cedar, Western Red	1300	1,000,000	120	145	950
Cedar, Yellow	1600	1,200,000	130	185	1050
Douglas Fir, Coast	2200	1,600,000	130	235	1450
Douglas Fir, Dense	2550	1,600,000	150	280	1700
Douglas Fir, Mountain	1900	1,400,000	120	220	1200
Fir, Amabilis	1300	1,100,000	100	160	1050
Hemlock, Eastern	1600	1,100,000	100	220	950
Hemlock, Western	1900	1,400,000	110	220	1200
Larch, Tamarack	1750	1,300,000	140	220	1250
Larch, Western	2200	1,500,000	130	235	1450
Pine, Jack	1600	1,100,000	120	200	1050
Pine, Lodgepole	1300	1,000,000	90	160	950
Pine, Red	1600	1,200,000	120	185	1050
Pine, Western White, Ponderosa, and Eastern White	1300	1,000,000	120	185	1050
Spruce, Eastern, Engelmann, and Sitka	1600	1,200,000	120	185	1050
Ash, Black	1450	1,100,000	130	220	850
Ash, White	2050	1,500,000	185	365	1450
Beech	2200	1,600,000	185	365	1600
Birch, Yellow	2200	1,600,000	185	365	1600
Elm, Slippery and White	1600	1,200,000	150	185	1100
Elm, Rock	2200	1,300,000	185	365	1600
Hickory, Bitternut and Shagbark	2800	1,800,000	205	440	2000
Maple, Sugar	2200	1,600,000	185	365	1600
Oak, Red and White	2050	1,500,000	185	365	1350

*These working stresses are for use with material containing no strength-reducing defects. In most instances timber used for structural purposes will contain strength reducing defects of one or more varieties, and it will be necessary to reduce these working stresses by an appropriate factor.

The above values are based on the strength of green material and are applicable, with certain adjustments, to material of any degree of seasoning.

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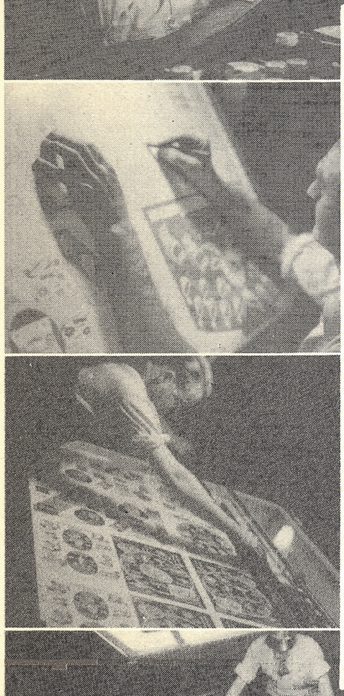

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